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Survey of Lead
in the Atmosphere
of Three Urban Communities

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Survey of Lead in the Atmosphere of Three Urban Communities

by
The Working Group on
Lead Contamination

American Petroleum Institute
Automobile Manufacturers Association
California State Department of Public Health
E. I. du Pont de Nemours and Company
Ethyl Corporation
Kettering Laboratory, University of Cincinnati
Public Health Service

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Air Pollution
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The ENVIRONMENTAL HEALTH SERIES of reports was established to report the results of scientific and engineering studies of man's environment: The community, whether urban, suburban, or rural, where he lives, works, and plays; the air, water, and earth he uses and re-uses; and the wastes he produces and must dispose of in a way that preserves these natural resources. This SERIES of reports provides for professional users a central source of information on the intramural research activities of Divisions and Centers within the Public Health Service, and on their cooperative activities with State and local agencies, research institutions, and industrial organizations. The general subject area of each report is indicated by the two letters that appear in the publication number; the indicators are

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PREFACE

In 1958, the Surgeon General of the Public Health Service was asked by manufacturers of tetraethyl lead (TEL) for the advice and guidance of the Public Health Service on the public health effects of increasing the maximum concentration of tetraethyl lead in motor gasoline from 3.0 to 4.0 milliliters per gallon. Although the Public Health Service has no legal authority to control the amount of lead antiknock in gasoline, the Surgeon General indicated that he would appoint a committee to advise whether the proposed increase might represent a hazard to public health. This committee (called the Advisory Committee on Tetraethyl Lead to the Surgeon General) concluded that such an increase in the TEL content of gasoline would not significantly increase the hazard to public health from air pollution.¹ It pointed out, however, that a conclusive answer was not possible because of the lack of sufficient relevant data.

The Advisory Committee on Tetraethyl Lead recommended to the Surgeon General that "The Public Health Service, in collaboration with manufacturers of tetraethyl lead, the petroleum industry, and other appropriate organizations, conduct studies to provide more definitive data on the levels and trends of atmospheric lead contamination in selected urban areas and of the body burden of lead of selected population groups." The Surgeon General convened a meeting to determine the interest of various groups in a cooperative study on atmospheric lead contamination. As a result a Working Group was formed to develop and execute a suitable program of studies.

The studies consisted of air sampling over a period of 1 year at a number of locations in Cincinnati, Los Angeles, and Philadelphia, and the gathering of blood and urine samples from selected population groups in these cities. The details of this program and the results obtained are the subject of this report.

PURPOSE

The purpose of the program undertaken by the Working Group on Lead Contamination was to:

1. Establish a baseline for the lead content of the atmosphere in urban areas and in the blood and urine of selected population groups.
2. Ascertain whether differences exist in levels of lead in the blood and urine of groups of individuals exposed to different amounts of lead in a community atmosphere.
3. Obtain data that would permit review of the potential harmful effects of existing lead concentrations in the atmosphere on the general population or segments of the population.

PARTICIPATING ORGANIZATIONS AND ACKNOWLEDGMENTS

The Working Group responsible for coordinating the project consisted of representatives of the following organizations: American Petroleum Institute, Automobile Manufacturers Association, California State Department of Public Health, E. I. du Pont de Nemours and Company, Ethyl Corporation, Kettering Laboratory of the University of Cincinnati, and U. S. Public Health Service. The names of the individual representatives are shown in the Appendix. The U. S. Public Health Service provided financial support for the Philadelphia program. The financial support for the Los Angeles study was provided jointly by the California State Department of Public Health and the U. S. Public Health Service. The Cincinnati survey was carried out by the Kettering Laboratory, with financial support supplied by the American Petroleum Institute, E. I. du Pont de Nemours and Company, and Ethyl Corporation.

In the Philadelphia area, the U. S. Public Health Service was assisted by the Philadelphia Health Department. In Los Angeles, assistance was rendered in the operation of the atmospheric sampling stations by the Los Angeles County Air Pollution Control District, California Institute of Technology, University of California at Los Angeles, Vernon City Health Department, Los Angeles City Health Department, and the Los Angeles County Arboretum.

Representatives of the agencies responsible for the day-to-day operation of the project rendered invaluable service. The efforts of these and many other individuals were essential to the completion of the program. Their contributions are gratefully acknowledged.

SUMMARY AND CONCLUSIONS

The Surgeon General of the Public Health Service, in response to a recommendation from an Advisory Committee on Tetraethyl Lead, appointed a Working Group from industry, a university, and State and Federal Governments, to investigate the problem of atmospheric lead in selected urban areas. This investigation consisted of a comprehensive sampling program for lead in the atmosphere of Cincinnati, Los Angeles, and Philadelphia, and for lead in the blood and urine of selected groups of persons in the population of these cities. Limited investigations were made of the concentration of atmospheric lead in heavy traffic and in a vehicular tunnel.

From June 1961 through May 1962 approximately 3,400 samples of particulate lead from the atmosphere were obtained at 20 sites in the three cities. It was found that:

1. The annual average concentration of lead in the atmosphere ranged from about 2 micrograms per cubic meter of air in the downtown and industrial area of Cincinnati, to about 1 in the outlying areas of that city. The values in corresponding areas in Philadelphia ranged from 3 to 1, and in Los Angeles from 3 to 2.
2. The average concentration of lead in all of the samples obtained in each city was 1.4 micrograms per cubic meter in Cincinnati, 1.6 in Philadelphia, and 2.5 in Los Angeles.
3. The highest concentrations of lead were found in the air during autumn and winter. The highest seasonal concentration of lead at any station was 2.4 micrograms per cubic meter in Cincinnati, 3.8 in Philadelphia, and 4.1 in Los Angeles.
4. The highest monthly concentration at any site was 3.1 micrograms per cubic meter in Cincinnati (October), 4.4 in Philadelphia (October), and 6.4 in Los Angeles (December).
5. The highest concentration of lead in any one sample was 6.4 micrograms per cubic meter in Cincinnati, 7.6 in Philadelphia, and 11.4 in Los Angeles.
6. The mean concentration of lead found in heavy traffic ranged from about 14 micrograms per cubic meter on Cincinnati streets, through approximately 25 on Los Angeles Freeways, to 44 in a vehicular tunnel.
7. The average content of lead in particulate matter for all samples was 1.7 percent in Cincinnati, 1.5 in Philadelphia, and 2.3 in Los Angeles.
8. Atmospheric lead concentrations varied during the day; highest concentrations occurred in the early morning.

The concentrations of lead found in the atmosphere in this study were consistent with those obtained during the same period by the National Air Sampling Network (NASN) of the Public Health Service. Data from the NASN show no consistent trend in the concentrations of lead in the atmospheres of the three cities during the past 5 years. Data obtained by the Kettering Laboratory indicate that in Cincinnati the trend has been downward since 1946.

The concentration of lead in the blood of approximately 2,300 individuals was determined, as was that in the urine of approximately 1,700 males within the same groups. Certain groups were selected because of their apparent exposure to different amounts of lead in the ambient air of the community in which they lived and worked. A few groups were representative of occupations that provided an opportunity for exposure to lead. Other groups were selected because they had certain chronic diseases that might conceivably have some bearing on ability to dispose of lead. Only 11 persons were found to have concen-

trations of lead in their blood equal to or in excess of 0.06 milligram per 100 grams of blood. A few values in excess of 0.06 are to be expected in a large sample of individuals representing a variety of exposures to lead.

Levels of lead concentration in the urine fell within the fairly narrow range that is presently defined as "normal."

The data on lead in the blood of the subjects were examined in relation to a number of variables. No relationship was found between levels of lead in the blood and age. Levels in females were slightly lower than those in males from comparable groups. In nearly all instances, the mean concentration of lead in the blood of smokers was slightly higher than that of non-smokers. There were no unusual findings concerning persons who were investigated because of chronic diseases.

A general trend was noted toward an increase in the concentration of lead in the blood of the groups of persons as they varied from rural to central urban areas in their places of residence and work. For example, those who lived and worked in rural or suburban areas had the lowest concentrations of lead in their blood, and it was in these areas that the lowest concentrations of lead were found in the atmosphere. Highest mean levels of lead in the blood were noted for groups who worked (and, in some cases lived) in areas characterized by higher concentrations of lead. These relationships were not as well defined for intermediate levels of lead in blood and in the atmosphere. Although these trends are influenced by factors not dealt with in this study, the correlation between the respective values at the extremes probably has validity in the causal sense.

In general, the results of both the aerometric and biological phases of the investigation confirm earlier findings based on more limited observations. It is believed that these results have established a baseline for future investigations of these types.

LEAD IN THE ENVIRONMENT

Lead occurs widely in the environment of man, both as a natural constituent and as a contaminant. Lead is taken into the human body in virtually all food and beverages and in respired air. It is a natural constituent of soil, water, vegetation, and animal life, and many human activities increase the lead in soil, in streams, and in the atmosphere. As a result of its ubiquitous nature, lead is a regular component of the minerals in living things generally and in man specifically. Further, the metabolism of lead in man has been studied intensively and a great deal has been learned about how the human body reacts to various types of exposure to lead. The sources of lead in the environment of man have been examined in detail in the past.

SOURCES OF LEAD IN THE ATMOSPHERE

Industrial

Lead is used in practically every type of industry. In this country, somewhat over 1,000,000 tons of lead are processed yearly.^{1,2} In addition to use in the production of lead alkyls, as in antiknock compounds, large quantities are used in the manufacture of storage batteries, for various construction purposes, in the production of paint pigments, and in the covering of cable. During 1961, American industry consumed lead as shown in Table 1.³

TABLE 1
INDUSTRIAL CONSUMPTION OF LEAD IN THE
UNITED STATES DURING 1961
(In short tons)

Storage batteries	352,000
Oil refining and gasoline	166,000
Construction (caulking)	116,000
Pigments	83,200
Cable	58,000
Solder	55,000
Ammunition	46,000
Printing (type metal)	28,000
Unclassified	100,800
Total	1,005,000

The large tonnage listed as unclassified indicates many uses for lead that are difficult to trace. While the consumption of lead has been very stable during the last 10 years, there have been changes in the amounts consumed by various industries; the amounts of lead for sheathing cable and for production of white house paints, for example, have decreased in the last decade because of the introduction of new materials.

Lead and its products are often processed from the molten state, giving rise to fume. Many lead products may also be produced as powders or involve products produced from powdered materials that may be dispersed into the air. The in-plant hazard associated with the processing of lead is often recognized, and most industries control this hazard. Although some lead is removed from industrial discharges by control devices, lead-bearing dusts and fumes escape to the outside air. Such discharges may contain as much as several milligrams of lead per cubic meter of air. Examples of concentrations of lead in in-plant air that may be discharged to the outside are shown in Table 2. All of these discharges are not continuous, but may be produced intermittently.

TABLE 2
CONCENTRATIONS OF LEAD IN THE IN-PLANT AIR
FROM A NUMBER OF OPERATIONS

Industry	Operation	Pb range, mg/m ³	Reference No.
Storage battery manufacturing	Dumping & mixing	0.35-6.06	32
	Pasting department	0.21-5.31	32
	Drying	0.12-3.21	32
	All	0.04-39.0	33,34,35,36
Paint manufacturing	All	0.39-48.6	31,37
Insecticide manufacturing	Blending room	up to 8	38
	Packaging room	1 to 11	38
Non-ferrous foundries	Over cupolas	4.46-12.0	39
	Tapping area	2.0	39
	Furnace room	0.51-0.75	39
	All	0.6-32	40,41
Painting & paint scraping	Hot riveting	6.4-8.2	42
Riveting	Lead smelting	0.01-2.45	43,44,6
Smelters	All	up to 5.35	45,46
Glass manufacturing			

Combustion of Fuel (Other than gasoline)

Air contaminated by fly ash or by soot derived from the combustion of coal may contain appreciable quantities of lead. In 1958, Savul reported finding from 0.005 to 1.67 ppm lead in coal and 25.5 ppm in the ash.⁴ In 1933, Dunn reported finding 4, 25, and 358 ppm of lead in soots from coal.⁵ Tomson found that fly ash from the combustion of coal contained 100 to 150 ppm lead.⁶ In 1961, Cholak reported concentrations ranging from 2 to 40 ppm with an average of approximately 11 ppm for 23 samples of coal used in the Cincinnati area.⁷ Lead emissions from dry-bottom power plants firing pulverized coal ranged from 0.06 to 0.33 milligrams per cubic meter of standard flue gas for three plants in Ohio and Pennsylvania.⁸ Although it is not known in what form lead is present in coal, the low melting points of some of the oxides and other lead compounds may result in the volatilization of lead during combustion. The ash of coal burned at 1000°C contains only 10 percent of the lead present when the combustion is carried out at 500°C.⁹

Motor Vehicles

One of the sources of lead in the atmosphere is the exhaust from gasoline-fueled vehicles. Essentially all of the motor gasoline sold in the United States contains alkyl lead compounds added to improve the antiknock quality of the fuel. During combustion, these lead compounds undergo thermal and oxidative breakdown and are discharged in the exhaust as inorganic salts.

The ability of alkyl lead compounds to increase the antiknock quality of fuels used in spark-ignition engines was discovered in the early 1920's.

Until 1959 the only alkyl lead compound used commercially was tetraethyl lead, although the ability of other alkyl lead compounds to increase antiknock quality was known. The relative effectiveness of the various alkyl lead compounds in imparting antiknock quality to gasoline depends on many factors including, to a large extent, the specific hydrocarbons that comprise the finished gasoline blends. Developments in the technology of petroleum processing in recent years have resulted in significant changes in the number and types of hydrocarbons in many of today's gasolines. Because of these changes and changes in other vehicle factors that also influence the type of antiknock quality required, certain refiners now find that alkyl lead compounds other than tetraethyl lead are more effective in raising the antiknock quality of their particular fuels. Antiknock compounds other than tetraethyl lead currently being used are tetramethyl lead, physical mixtures of tetraethyl lead and tetramethyl lead, and equilibrium mixtures of a catalyzed redistribution reaction of tetraethyl lead and tetramethyl lead. The amount of each of the alkyls in the latter mixture depends on the percentage of tetraethyl and tetramethyl lead used in the reaction. These alkyl lead compounds are present in today's gasolines in widely varying concentrations, the maximum in motor gasolines being 4.23 grams of lead per gallon (equivalent to 4 milliliters of tetraethyl lead per gallon of gasoline) in accordance with an agreement between the suppliers and users that has the concurrence of the Office of the Surgeon General of the U. S. Public Health Service. During the period of this investigation, the national use of antiknock compounds containing alkyl lead averaged a little over 2.0 grams of lead per gallon of motor gasoline.

The total consumption of lead metal in antiknock compounds in domestic motor gasolines for the past 10 years is shown in Table 3 with the average lead content per gallon during the same period.

TABLE 3
CONSUMPTION OF LEAD IN ANTIKNOCK COMPOUNDS
IN DOMESTIC MOTOR GASOLINE*

Year	Total lead metal, millions of pounds	Average lead content, g/gal
1953	234	2.28
1954	248	2.34
1955	276	2.37
1956	288	2.44
1957	282	2.38
1958	253	2.12
1959	258	2.06
1960	263	2.04
1961	256	1.98
1962	280	2.08

*Source: Ethyl Corporation and E. I. du Pont de Nemours and Company.

Commercial lead antiknock fluids of all types contain halogens designated as scavengers that serve to reduce the accumulation of decomposition products of the lead alkyls in certain critical areas of the engine combustion chamber. Scavenger concentrations are expressed in terms of theories. One theory is defined as the amount of the active halogen ingredient required to react chemically with all of the lead present in the fluid. The most commonly used commercial fluid contains 0.5 theory of ethylene dibromide and 1.0 theory of ethylene dichloride.

When gasoline containing lead antiknock fluids is burned in an engine, the alkyl lead compounds decompose at the high temperatures and pressures developed by the combustion process and the decomposition products, lead oxides, act to inhibit chain reactions that would otherwise result in uncontrolled detonation or knock. The decomposition products then react with the scavengers present and these resultant products are the materials that are carried into the exhaust system along with the other combustion products. These inorganic lead compounds are primarily $\text{PbCl} \cdot \text{Br}$, alpha and beta forms of $\text{NH}_4\text{Cl} \cdot 2\text{PbCl} \cdot \text{Br}$, and $2\text{NH}_4\text{Cl} \cdot \text{PbCl} \cdot \text{Br}$ with minor amounts of PbSO_4 and $\text{PbO} \cdot \text{PbCl} \cdot \text{Br} \cdot \text{H}_2\text{O}$. When phosphorous additives are present in the fuel, up to one-fifth of the exhausted lead may be present as $3\text{Pb}_4(\text{PO}_4)_3 \cdot \text{PbCl} \cdot \text{Br}$.

Studies of the lead particulates leaving the tailpipe have shown that from 70 to 80 percent of the metallic lead used by a vehicle will eventually be exhausted to the atmosphere over 20,000 to 30,000 miles of city and country driving.¹² The balance remains in the engine itself, in the lubricating oil and oil filter, and in the vehicle exhaust system. The amount and particle size of inorganic lead leaving the tailpipe of a vehicle at any given time is dependent on many factors including the operating mode at the instant, the short and long term type of preceding operation, the age of the vehicle and its exhaust system, and engine and exhaust system design features. These studies have also shown that in city-type operation less lead is exhausted than in highway-type service. In city operation from 20 to 60 percent of the lead burned in the combustion chamber is exhausted from the tailpipe in inorganic form depending upon the amount of lead particulates accumulated in the exhaust system as the result of the preceding operating history. Of this from one-half to three-fourths of the lead is in the particle size range that might be expected to remain air-borne.

Although essentially all of the lead discharged by vehicles is exhausted in the form of inorganic particles, small percentages of the alkyl lead compounds blended in gasoline may reach the atmosphere through escape of fuel vapors. Volatile fuel vapors can be lost from vents on the carburetor and fuel system and are displaced from the tank during refueling. The concentrations of alkyl lead compounds in the vapor

are lower than those in the original gasoline since these compounds are less volatile than gasoline and tend to remain behind in the unevaporated portion. Some vaporized fuel containing alkyl lead compounds escapes also in the blowby gases that are forced past the pistons and discharged from the crankcase. (With the installation of positive crankcase ventilation devices, this source will eventually be eliminated.) Moreover, in the normal combustion process a very small percentage of the fuel introduced is not completely burned. This unburned fuel contains some alkyl lead compounds. This lead, however, is mixed with hot exhaust gases and contacts components of the engine and exhaust system at high temperature; considerable decomposition results, since the alkyl lead compounds begin to decompose at temperatures as low as 400°F. All organic lead compounds, even at low concentrations, are light-sensitive and hence are subject to photochemical decomposition once they reach the atmosphere.

Other Sources

Soils generally contain lead, and therefore particles of soil that become airborne contribute small amounts of lead to the atmosphere. The lead content of soils varies with the geology of the area. Goldschmidt reported that the average in the earth's crust is 16 ppm.^{11,12} Others have reported values ranging from 0.05 to several thousand parts per million near smelters. Cholak and co-workers reported that the lead content of soil in the Cincinnati area varied from 16.4 to 360 ppm. The higher concentrations were found in soils of the older residential areas with a longer history of repainting of dwellings.¹ Prince, in 1957, reported that the lead content of the loamy soil types in New Jersey varied from 13.9 to 95.7 ppm.¹³

SOURCES OF LEAD IN MAN

Ingestion

It has been reported that the lead content of the composite food of adult citizens of the United States ranges from under 0.1 milligram to more than 4.0 milligrams per day, and averages approximately 0.3 milligram per day, dependent upon the amount and variety of food consumed by the individual.¹⁴ The natural or treated water supplies available for use in cities in the United States usually contain about 0.01 to 0.03 milligram per liter.¹⁵ For an average intake of water ranging from 1 to 3 liters, this would amount to 0.01 to 0.09 milligram of lead per day.

The absorption of lead from the alimentary tract is somewhat less than 10 percent of that ingested. Even when a compound of lead has been dissolved prior to its experimental ingestion, only 10 to 15 percent of it is absorbed, when the dosage per day does not exceed 1 to 4 milligrams.¹⁶ A larger percentage may be absorbed when the dosage in the

alimentary tract is considerably higher than that indicated above. Acute poisoning may develop promptly following the ingestion of a large dose of a soluble salt. Lead poisoning may also develop within several weeks when the quantity of somewhat soluble lead ingested per day by an adult is of the order of 6 to 10 milligrams.¹⁷

Inhalation

The monthly average concentration of lead in the atmospheres in large U. S. cities varies from about 1 to 6 micrograms per cubic meter. Since a person breathes approximately 15 cubic meters of air per day, the lead inhaled from the general atmosphere of cities varies from about 0.01 to 0.10 milligram per day.

It is not possible to describe the behavior of particulate compounds of lead in the human respiratory tract in a precise manner. There is sufficient evidence, however, to indicate the general pattern of pulmonary retention of particulate matter by particle size.

Particles larger than 5 microns in diameter settle fairly rapidly and do not usually constitute a large part of the suspended particulate matter in the atmosphere. When such particles are inhaled they are trapped in the nostrils or nasopharynx or are deposited upon the tracheo-bronchial mucosa. Through the secretion of mucous and the action of the cilia, they move to the pharynx, from which they are evacuated in the mucous discharges of the nose and throat, or are swallowed. Some portion of that which remains within the upper respiratory tract for a time, or is swallowed, is absorbed.

Particles of lead compounds within the range of 2 to 5 microns in diameter are deposited in various parts of the respiratory tree. Few, if any, reach the alveoli. Particles less than 1 micron in diameter reach the alveoli, and some are retained. Recent work by Robinson¹⁸ indicates that "... a typical size distribution for lead aerosol would be one with a mass median equivalent diameter of 0.2 micron with 25 percent of the mass being accounted for by particles with an equivalent diameter of less than 0.1 micron and another 25 percent of the mass being found in particles larger than 0.5 micron."

The absorption of lead in the respiratory tract depends on a number of factors, including the solubility of the compound in the epithelium and endothelium of the respiratory tree, the dimensions of the dispersed particles of the compound, and the surface relationships between the particles and the respiratory membrane. Experimental evidence has shown that the sesquioxide is rapidly absorbed^{17,19} in the lung, and certainly the chloride or bromide or the double halogen salt, as well as many other compounds, would be absorbed readily.

Kehoe of the Kettering Laboratory reported in 1960 that 35 to 50 percent of finely divided, inhaled lead (particles of lead sesquioxide under 0.2 micron in diameter at concentrations on the order of 150

micrograms per cubic meter) is retained in the lungs, and that all of this retained lead is eventually absorbed.¹⁷ More recent unpublished data obtained by the Kettering Laboratory show that at concentrations of 10 micrograms per cubic meter of air, somewhat less than 20 percent of lead sesquioxide is retained.

Smoking

The quantity of lead in cigarettes and tobaccos has been the subject of speculation as to the significance of the absorption of lead by smokers. Because of the use of lead-bearing insecticides, it is not unusual to find occasional samples of tobacco with a fairly high lead content. As early as 1921, Cadenhead, investigating a possible source of lead poisoning, reported the finding of 0.2 gram of lead in a pipeful of tobacco; at the same time he reported that only 76 micrograms (0.038 percent) was in the smoke.¹⁸ In 1937, the lead concentration in Canadian cigarettes was reported to average 22 ppm and to range from 7.5 to 27.5 ppm.¹⁹ In 1957, English tobaccos were found to contain lead concentrations of 4.8, 5.1, and 36 ppm respectively in pipe, cigarette, and cigar tobaccos.²⁰ These levels were considerably lower than those reported in 1951 when the same materials averaged 96, 143, and 414 ppm, respectively.²¹ In 1961, Kehoe reported that lead in the ash of smoked cigarettes averaged 14 micrograms per cigarette.¹⁷

Several reports indicate that tobacco smoke contains very little of the lead originally present in the tobacco. In 1939, it was reported that only one-fifteenth of the total lead in cigarettes was found in puffed smoke.²² A more recent analysis of five different brands of cigarettes indicated that the lead content per cigarette averaged 13 micrograms, of which an average of only 0.6 microgram (4.9 percent) appeared in the smoke.^{17,23} Cogbill and Hobbs, investigating the transfer of metallic constituents of cigarettes to the smoke, also concluded that the metallic constituents remain in the ash although small quantities may be vaporized and appear in the smoke.²⁴

EFFECT OF LEAD ON MAN

Intake of Lead

A normal adult may take into his body about 0.14 to 0.45 milligram of lead per day. The largest portion of this lead is in food and beverages, which may contribute, on the average, about 0.12 to 0.35 milligram per day.¹⁷ The amount of lead taken in with the inspired air may range from about 0.01 to 0.10 milligram per day.

Output of Lead

Roughly 90 percent of the ingested lead traverses the alimentary tract unabsorbed and is discharged in the feces. To this unabsorbed

lead in transit is added the unresorbed portion secreted into the alimentary tract in the biliary, digestive and mucous secretions. The result is that the amount of lead in the feces is practically equivalent to that in food and beverages ingested.

As discussed earlier in this report, 20 to 50 percent of finely divided inhaled lead particles is retained; consequently, 50 to 80 percent is exhaled.

The amounts excreted in the urine over considerable periods of time average from 0.02 to 0.04 milligram per day.¹⁷ Significant but ill-defined quantities may be excreted in the sweat and in other aqueous, mucous, and lipoid secretory discharges from the body. Further small quantities of lead are shed regularly in falling hair, desquamating skin, and clipped nails.

Body Burden of Lead

In persons of all ages (beyond early infancy, for which data are scanty) in the United States, appreciable quantities of lead are widely distributed throughout the body tissues. Concentrations in the soft tissues are low, ranging from about 20 micrograms per 100 grams of striated muscle to about 200 micrograms per 100 grams of liver; those in the skeleton are relatively high, ranging from about 400 micrograms to about 1200 micrograms per 100 grams in the ribs or vertebrae, to two or three times these levels in the femur. (These concentrations are expressed in terms of the fresh or formalin-fixed, rather than the dry or ashed tissues).¹⁴ At first glance, lead in the body in such concentrations suggests a progressive cumulative process whereby some of the lead absorbed from the environment is retained in the body regularly. To a limited extent this may be so, but present evidence indicates that an approximate balance between intake and output is arrived at early in life.

Equilibrium in a normal individual may be disturbed by an increase or decrease in the intake of lead. Under such circumstances, the body burden of lead may increase or decrease. Balance experiments have shown that changes in the intake and output of lead occur from time to time in response to changes in the environment of the individual. The most obvious of such changes, aside from entering upon or terminating employment in a lead-using industry, is altering the quality or quantity of food. Anything that affects the appetite or promotes a wider or narrower selection of food alters appreciably the intake of lead in food or beverages, sometimes several fold. Another possible change is that due to differing lead levels in the atmosphere to which the subject is exposed.

Accumulation of Lead in Man

With a significant increase in the intake of lead, a response occurs that is characterized by an increase in the absorption of lead, by in-

creased concentrations in the various tissues and fluids of the body, and by an increase in the excretion of lead from the body in the feces, urine, and sweat.

If a sufficient increase in the intake of lead continues steadily for a long time, the lead content of the body increases at a steady rate over a corresponding period of time until equilibrium is reached. The excretion of lead also increases, but not, for at least several years, at a rate equivalent to the increase in the rate of absorption; hence accumulation in the body occurs at a practically constant rate.¹⁴ In time, the body burden may reach a threshold of danger; i.e., a level at which intoxication may occur. It does not follow, necessarily, that when such a level or one much higher has been reached, intoxication will occur in an individual or in a large proportion of the individuals within a group. An individual with a remarkably high body burden of lead may remain in apparently excellent health. Cases of illness are noted only when the concentration of lead in the blood reaches or exceeds the danger threshold, generally considered to be about 0.08 milligram of lead per 100 grams of blood. By comparison, investigations of large numbers of persons who have not been subjected to discoverable exposures to lead in industry or to other unusual conditions indicate that the usual upper limit is about 0.06 milligram per 100 grams of blood.

When the intake of lead is increased intermittently, the period of relatively rapid absorption results in accumulation of lead in the tissues, while the alternate period results in an overall loss of lead from the body. If the overall severity of the exposure remains fairly uniform, the quantities of lead lost from the body during the period of freedom from exposure eventually come to be nearly equivalent to the quantities of lead that accumulate during the periods of exposure. This state of equilibrium is indicated by an essentially steady excretion of lead in the urine and concentration of lead in the blood. Where the exposure to lead is fairly constant, this steady state continues without significant change for many years. The individuals so exposed continue to excrete lead in the urine at a constant level, and maintain a correspondingly constant concentration of lead in the blood. No evidence of a progressive increase in the body burden of lead develops in persons so exposed, even after many years. If the blood levels are below the danger threshold, lead poisoning does not occur. Thus, in various industrial operations, the severity of exposure to lead is indicated by the concentrations of lead in the urine or blood.

Lead Intoxication

There are three forms of lead poisoning due to the absorption of lead. The most common form of the disease manifests as a mild or severe dysfunction of the alimentary tract, with loss of appetite, con-

stipation, colic (as the dominant feature), and general weakness and malaise.

Second, and much less frequent today, is the neuromuscular syndrome, characterized by weakness and a degree of atrophy of the extensor muscles of the forearms, or by paralysis of such muscles and more striking atrophy.

The third is lead encephalopathy, which occurs frequently among infants and young children but only rarely in industrial lead poisoning.

Associated with each of these three forms of lead intoxication, in greater or lesser degree, are certain abnormalities of the blood that arise from the effects of lead upon certain of the structural and chemical processes of hematopoiesis. Thus juvenile forms of erythrocytes, reticulocytes, and erythrocytes containing excessive quantities of granular basophilic material appear in the peripheral blood, while increased quantities of certain porphyrins appear in the blood and in the urine as an expression of abnormalities in the synthesis of hemoglobin.

INVESTIGATIONS IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA

The program to survey lead in urban communities included a systematic determination of lead concentrations in the air of Cincinnati, Los Angeles, and Philadelphia and of lead concentrations in the urine and blood of at least 500 selected residents of each of these communities. Samples of atmospheric lead were collected continuously from June 1961 through May 1962. Biological samples were collected in Philadelphia during March and April, 1961; in Cincinnati during 1962-63, and in Los Angeles during 1961-62.

ATMOSPHERIC SAMPLING AT FIXED STATIONS THREE-CITY STUDY

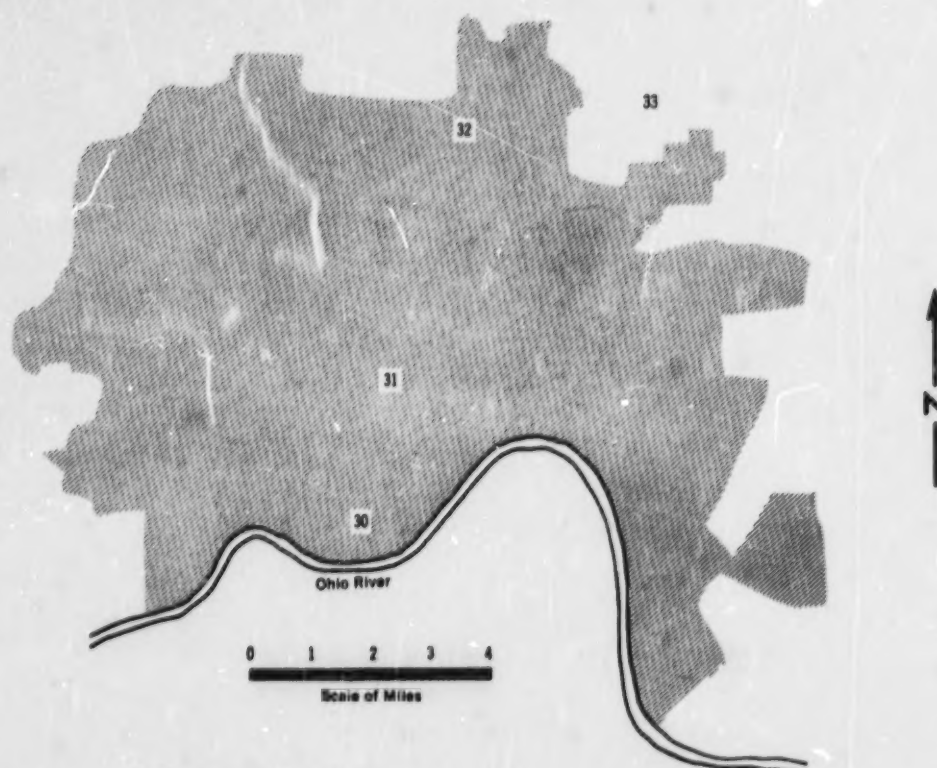
The selection of cities for investigation involved a number of factors. It was desirable to include cities for which available data indicated that the atmospheric lead levels were among the highest in the country and, therefore, the exposure of the population would be the greatest. A range of geographical and climatological areas was also considered desirable. The extensive nature of the atmospheric and biological sampling, financial considerations and the availability of trained manpower limited the choice and number of cities. It was believed that Cincinnati, Philadelphia and Los Angeles best met the criteria. Also data from earlier lead measurements in Cincinnati and Los Angeles would be useful in the present study.

Aerometric Methods

Locations of Sampling Sites: Sites were selected to represent four geographical and land-use classifications: rural, residential, commercial, and industrial. At least one air sampling station was established to determine the atmospheric concentration of lead in each classification. A total of four stations was used in Cincinnati, and a total of eight was used in both Los Angeles and Philadelphia.

Uniform criteria for selection of individual sampling sites provided that sites be representative of the surrounding area and near locations from which biological samples were collected. Before final selection was made, each site in the three cities was evaluated according to height above ground surface, number of obstructions, and representativeness of the site to the area.

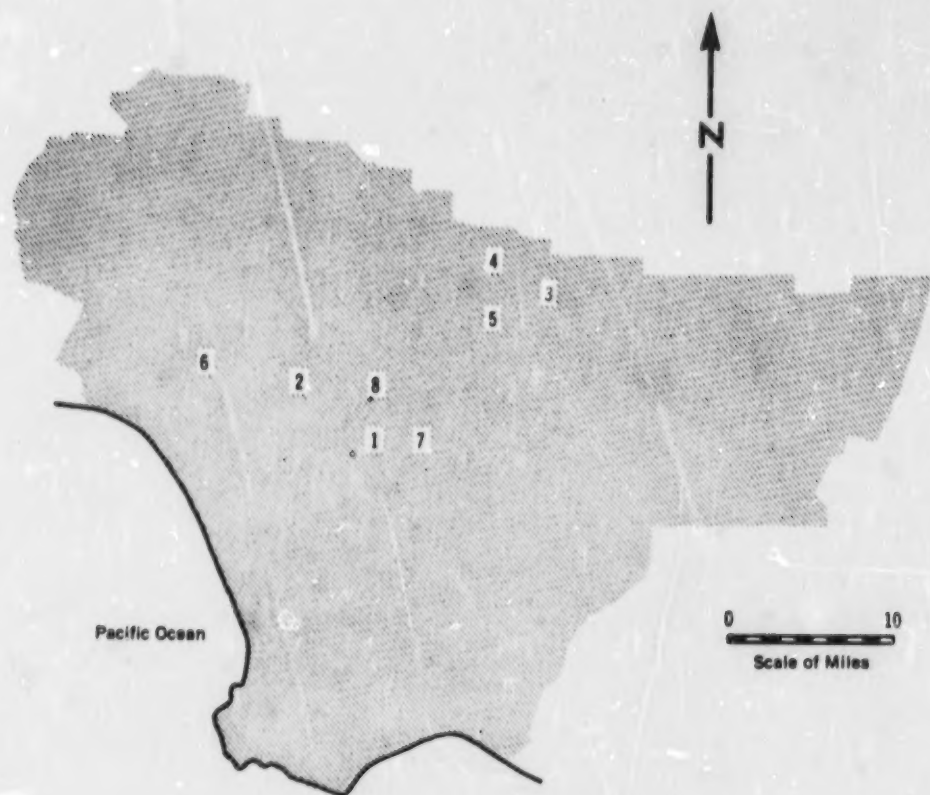
The locations of sampling sites in the three cities are shown in Figures 1, 2, and 3.



Site No.	Classification	Height above ground, ft.	Location
30*	Commercial	70	Cincinnati Main Library
31*	Residential	40	Kettering Laboratory
32*	Industrial	45	Vine and Seymour Fire Station
33*	Rural	15	French Park

*Equipped with sequential tape sampler.

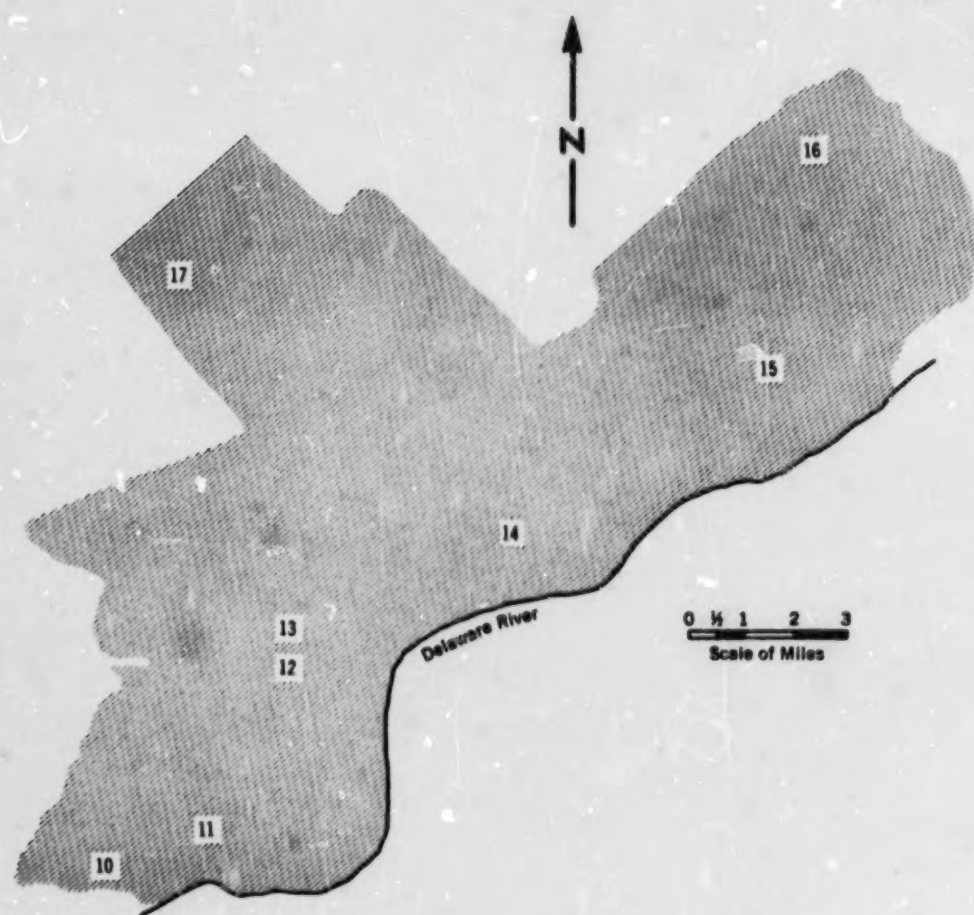
FIGURE 1
LEAD SAMPLING SITES IN THE CINCINNATI AREA



Site No.	Classification	Height above ground, ft.	Location
1*	Commercial	80	Downtown Los Angeles—County Air Pollution Control District
2*	Commercial	5	West Los Angeles—County Air Pollution Control District
3*	Rural	5	Arcadia—County Aboretum
4	Residential	10	Pasadena—County Air Pollution Control District
5	Residential	60	Pasadena—California Institute of Technology
6	Residential	40	Inglewood—University of California at Los Angeles
7*	Industrial	5	Vernon—Vernon City Health Dept.
8	Commercial	95	Downtown Los Angeles—Los Angeles City Health Dept.

*Equipped with sequential tape sampler.

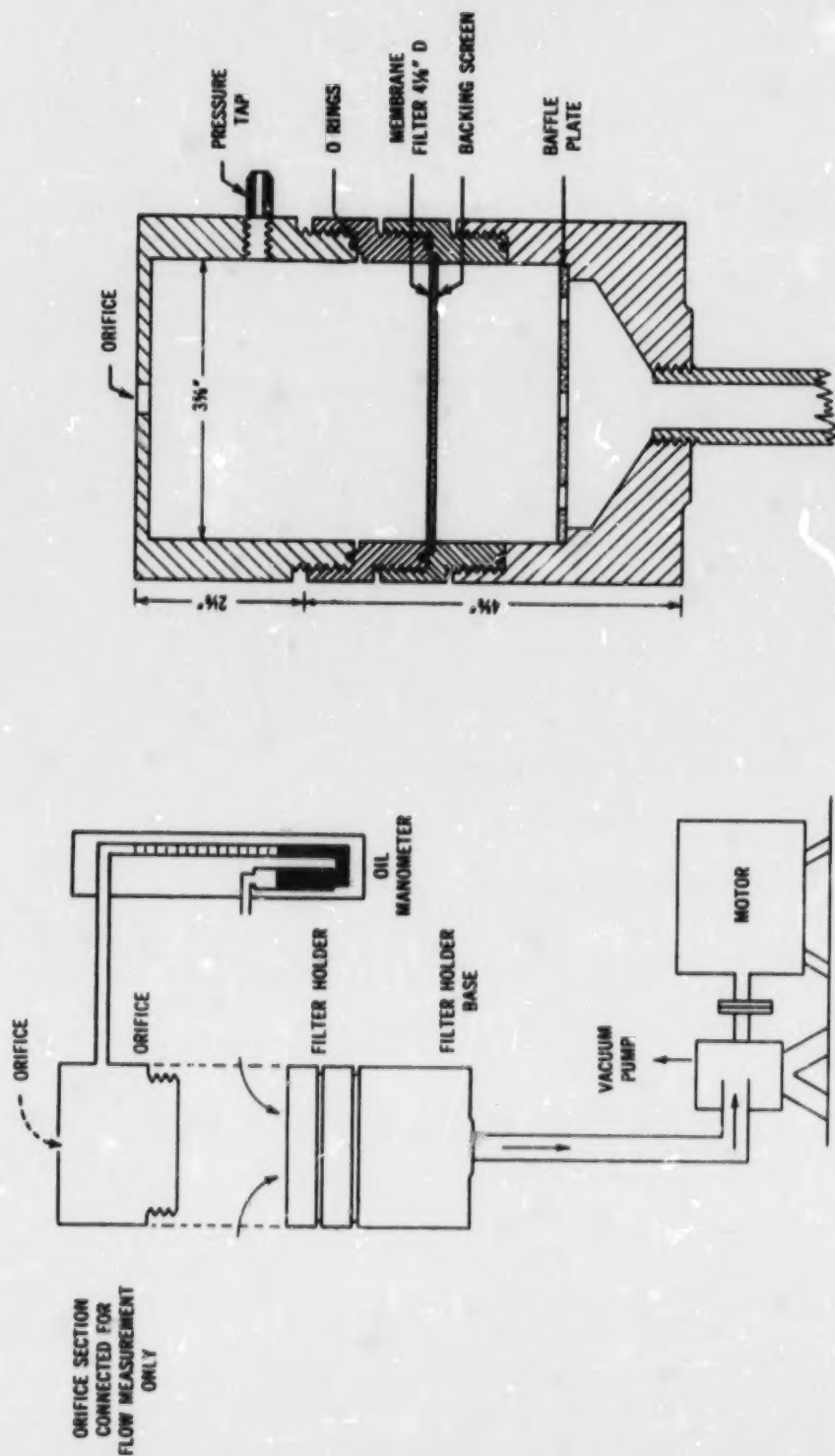
FIGURE 2
LEAD SAMPLING SITES IN THE LOS ANGELES AREA



Site No.	Classification	Height above ground, ft.	Location
10*	Commercial	70	International Airport, USWB
11*	Mixed	5	U. S. Naval Hospital
12*	Commercial	50	Philadelphia City Health Dept.
13*	Commercial	5	15th and Market
14*	Industrial	25	Air Pollution Control Laboratory
15*	Residential	12	Pennypack Home Owners Assn.
16*	Rural	10	Private Residence
17	Rural	10	Eva and Dearnley Water Treatment Plant

*Equipped with sequential tape sampler.

FIGURE 3
LEAD SAMPLING SITES IN THE PHILADELPHIA AREA



DETAIL OF FILTER HOLDER WITH ORIFICE IN PLACE

FIGURE 4
SCHEMATIC OF EQUIPMENT FOR SAMPLING INORGANIC LEAD

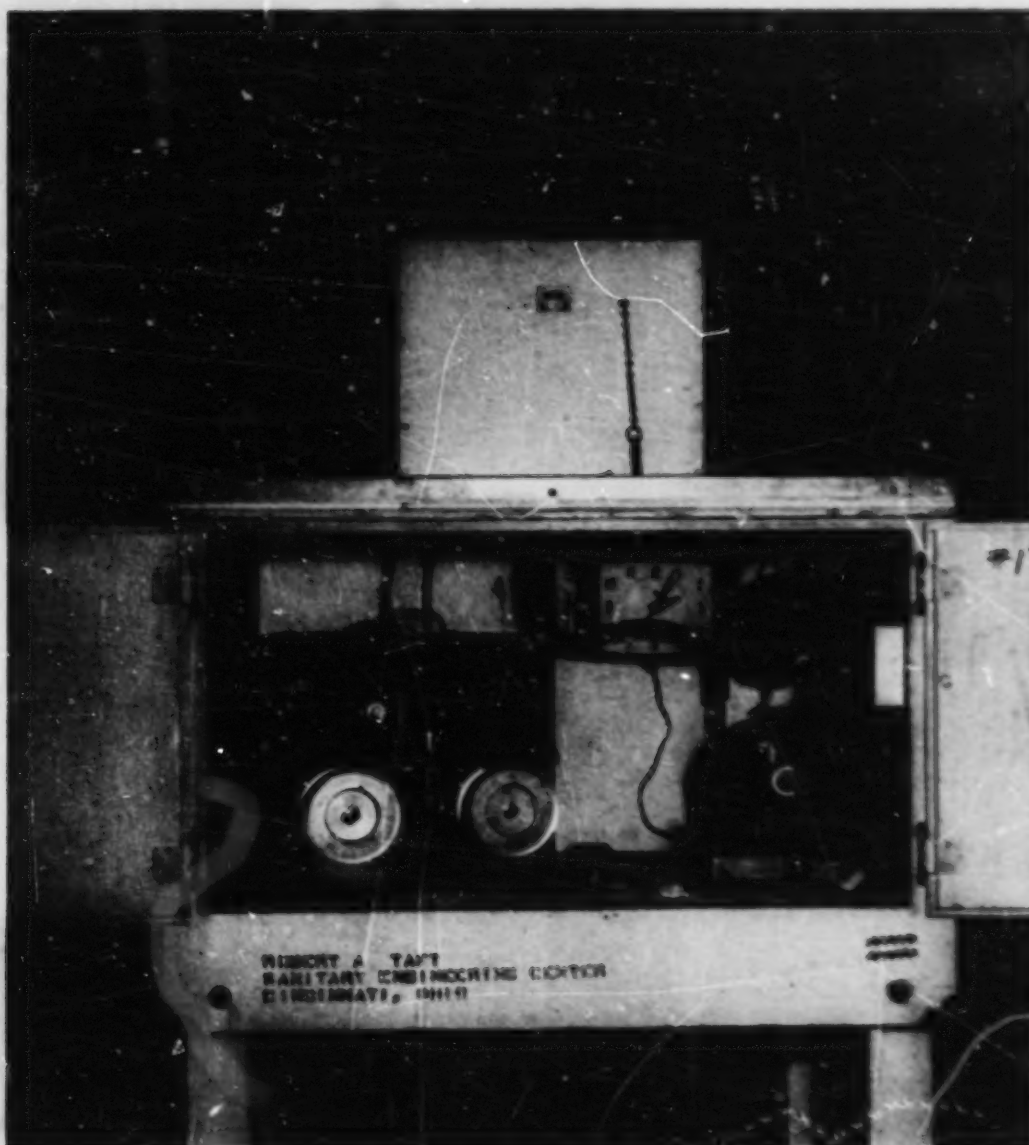


FIGURE 5
EQUIPMENT FOR SAMPLING INORGANIC LEAD

Sampling equipment: The atmospheric lead sampler included an orifice-type metering device for determining initial and final air flows, a stainless-steel filter holder to contain a $4\frac{1}{8}$ -inch-diameter membrane filter, a vane-type pump and motor capable of supplying a free flow of 5.9 cfm, a cooling blower, and auxiliary electrical equipment. An air-flow diagram and a detailed drawing of the filter holder and orifice are shown in Figure 4.

At some of the installations, diurnal variations in lead concentrations were determined by use of sequential tape samplers (Figure 5). These instruments sampled at 0.25 cfm on either a 2- or 4-hour cycle with Whatman No. 4 tape. Stations equipped with these tape samplers are indicated in Figures 1, 2, and 3.

The pore diameter of the Millipore filter (Type WS) used in these studies was 3.0 microns. To check its efficiency, an 8- by 10-inch WS filter was backed by a Millipore WH filter (pore diameter 0.45 micron). In one test, 1000 cubic meters of air was sampled over 4 days, and in another test, 3500 cubic meters of air was sampled over 14 days. In both tests, over 99 percent of the lead was collected on the first WS filter and less than 1 percent was collected on the backup WH filter.

The collection efficiency of Whatman No. 4 filter tape used in the sequential tape samplers is reported by Smith and Surprenant¹⁰ to be essentially 100 percent for particles greater than 2 microns in diameter, about 65 percent for particles 0.8 to 2 microns, and about 25 percent for particles less than 0.8 micron in diameter. Samples were collected on both Whatman No. 4 and Millipore WS filters. The Whatman No. 4 filters regularly gave lower values, which evidenced their lower collection efficiency. Consequently, samples collected on the Millipore filters were used to determine absolute lead values, and the samples collected on Whatman filter tapes were used to determine relative diurnal variations.

Sampling methods: Samples of particulate matter were collected on the Millipore WS filters during periods of 24, 48, or 72 hours at a nominal flow rate of 4 cfm. This sampling was continuous for the duration of the investigation. As a rule, filters were changed on Mondays, Wednesdays, and Fridays. No difficulties were experienced in Cincinnati or Philadelphia with reduced flows caused by the plugging of the filter within the 48- or 72-hour periods. In Los Angeles, however, the filter became plugged and required more frequent changes, sometimes in less than 24 hours. The problem was accentuated during periods of photochemical air pollution.

The sequential samplers were operated on 2- or 4-hour cycles for the duration of the investigation, the tapes being changed on Fridays.

Analytical methods: The Public Health Service acted as a clearing house to coordinate the activities of the participating laboratories. These were the Air and Industrial Hygiene Laboratory of the California State Department of Public Health, the Keitering Laboratory of the University of Cincinnati, and laboratories of the Divisions of Air Pollution and Occupational Health of the Public Health Service.

Lead concentrations in particulate matter were determined by the dithionite method,¹¹ modified slightly to suit the experience of each laboratory. To ensure uniformity of the 4- $\frac{1}{4}$ -inch membrane filters, all

were procured by the Public Health Service clearing house. Out of each package of 50 filters, one was analyzed for lead content to determine the acceptability of the batch and to provide a blank value. The filters were numbered serially, weighed after conditioning in a controlled atmosphere, inserted in numbered plastic boxes, and shipped with record forms to the individual laboratories.

In the three cities, the filters were loaded by use of plastic-tipped tweezers into the special filter holders, which were placed in plastic bags with the appropriate record for transportation to the sampling site. At the sampler, the filter holder was exchanged for the used filter and holder. Final air flow values for the used filter and initial flow values for the new filter were obtained at that time. The used filters were transferred from the plastic bags to a plastic petri dish for shipment to the clearing house.

The membrane filters were returned to the clearing house, and again weighed after conditioning to determine total particulate matter deposited thereon. A special template was used to divide the filter into 10 equal wedges. Five wedges were returned to the respective laboratories, and the other five were retained by the clearing house. The participating laboratories then analyzed one or more wedges of the filter and reported results to the clearing house on the record form in micrograms of lead per cubic meter of air. The remaining wedges were retained for possible future studies involving other atmospheric constituents.

Whatman No. 4 tapes from the sequential tape samplers were processed by the participating laboratories. The tapes were divided to provide six 4-hour or twelve 2-hour samples per day on a seasonal basis (December through February, March through May, June through August, and September through November). At least 1 inch of each strip of tape between the deposited spots was retained as a blank.

Interlaboratory comparisons: Each participating laboratory performed the chemical analyses of the samples from a particular city; i.e., Los Angeles samples were analyzed by the California laboratory, Cincinnati samples by the Kettering Laboratory, and Philadelphia samples by the Public Health Service laboratory.

Although the determinations were made in essentially the same manner by all three laboratories, minor differences in techniques suggested the possibility that results might not be comparable. To determine the extent of variability, if any, the clearing house set up a program in which each laboratory performed lead determinations on (1) synthetic samples, (2) sections of membrane filters on which atmospheric particulates had been collected, (3) about 5 percent of all the atmospheric samples collected during this investigation.

Prior to field sampling, each laboratory performed lead determina-

tions on synthetic samples spiked with a known amount of lead (5.0 micrograms). Although the results for individual samples ranged from 4.6 to 5.5 micrograms, the means of the values reported by the three laboratories varied only from 4.8 to 5.1 micrograms. The differences were not statistically significant. The standard deviation for an individual lead value was the same for all laboratories—0.15 microgram.

When sections of membrane filters on which particulate matter had been collected were analyzed, agreement among laboratories was not as good as with the synthetic sample. Investigations established that this difference was not due to differences in the digestion procedures used by the three laboratories. Special care was taken to ensure that wedges cut from a given filter were of equal size. It was also found that the lead on a given filter was uniformly distributed so that a given wedge would not show more than its proportionate share of lead. In spite of these checks and precautions, the differences in analytical results remained greater with particulate samples than with synthetic samples. The reasons for this are not known, but may arise from a lack of discrimination of the method in analyzing the complex particulate sample as compared to a soluble, essentially pure lead compound in the synthetic sample.

When atmospheric samples from the three-city survey were used in the comparison program, each laboratory was asked to analyze three wedges from each filter. The analytical variability in terms of standard deviations, which was about the same for the three laboratories, was not related to the amount of lead on the filter. The pooled estimate of the standard deviation of an individual lead determination was about 60 micrograms of lead per filter. On the basis of the pooled estimate, the standard deviation varied from about 30 percent for a sample containing 200 micrograms of lead to only 3 percent for a sample containing 2000 micrograms of lead.

As a continuing check on the interlaboratory comparability of lead determinations, about 5 percent of the group of particulate samples collected during the year-long investigation were reanalyzed. Each laboratory was asked to analyze a single wedge from each filter in the 5-percent group of samples. Of course one of the three laboratories had already performed a lead determination on each filter. The 5-percent group of samples involved a total of 186 particulate filters.

Results of analysis of the 5-percent group of samples are summarized in Table 4. Throughout this period the results reported by the California laboratory tended to be below the average for all three laboratories by about 9 percent. Determinations reported by the Public Health Service laboratory were about 9 percent above the average, and values reported by the Kettering Laboratory were the same as the average for all three laboratories.

The differences were not large enough to affect the comparability of

the results. They can, if desired, be taken into account when assessing the data from the various laboratories.

Only limited comparisons were made for lead in biological samples. In the analyses of blood and urine, there was generally good agreement among the laboratories.

Data handling: The clearing house transferred all aerometric data to punch cards, which were processed by the Division of Air Pollution. An electronic computer was used to prepare the data tabulations for analysis and inclusion in this report.

TABLE 4
INTERLABORATORY COMPARISON OF SAMPLES

Month	Average percent difference from the mean		
	Laboratory		
	California	PHS	Kettering
June-1961	- 3	+10	- 7
July	- 3	+ 9	- 6
September	-14	+17	- 3
October	-21	+17	+ 4
December	-12	+ 7	+ 5
February-1962	- 3	+ 1	+ 2
April	- 4	0	+ 4
All months	- 9	+ 9	0

Concentrations of Air Pollutants

Suspended particulates: Concentrations of suspended particulates obtained as part of the atmospheric lead sampling program are given in Tables 5, 6, and 7 and Figure 6.

Mean concentrations of suspended particulates for all samples in each city were 81 micrograms per cubic meter in Cincinnati, 117 in Los Angeles, and 105 in Philadelphia (Table 5).

The average monthly concentrations obtained from samples from all sites in Philadelphia and Los Angeles were highest in October and in Cincinnati in May (Table 5 and Figure 6). The value for Cincinnati was 98 micrograms per cubic meter, for Los Angeles, 144, and Philadelphia, 125; Figure 6 shows that lesser peaks of average monthly concentrations occurred in Los Angeles in January and April. Philadelphia had secondary monthly peaks in February and May, and Cincinnati showed a secondary peak in October.

The highest single concentration of suspended particulates was 237 micrograms per cubic meter in Cincinnati, 306 in Philadelphia, and 509 in Los Angeles. (Not shown in any Tables included in this report.)

TABLE 5
ANNUAL, SEASONAL, AND MONTHLY MEAN SUSPENDED PARTICULATE CONCENTRATIONS IN
CINCINNATI, LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	Site	SEASON					MONTH											
		Annual	Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cincinnati	All	81	87	81	74	82	90	82	88	79	95	70	70	76	77	74	74	98
	30	98	106	100	93	96	111	97	109	94	118	89	87	93	98	88	89	111
	31	77	79	79	70	79	81	76	80	79	93	65	64	72	75	74	69	94
	32	95	100	98	84	98	104	94	103	95	118	81	81	88	83	83	92	117
Los Angeles	33	54	61	48	51	57	63	61	59	47	52	46	48	52	52	51	48	72
	All	117	121	128	116	105	129	118	116	101	144	139	115	134	98	84	135	96
	1	124	126	145	118	109	133	123	121	115	159	161	129	143	81	93	143	91
	2	108	100	130	110	90	104	98	98	104	150	137	130	108	93	77	119	75
	3	115	131	125	111	91	150	126	118	106	144	125	105	125	104	78	114	81
	4	110	133	105	101	101	143	128	128	88	118	110	82	105	115	75	141	87
	5	106	127	112	86	99	136	125	119	96	123	118	89	95	75	80	131	87
	6	98	95	98	101	100	103	87	95	76	115	105	87	102	114	59	126	113
	7	142	127	156	168	119	125	135	121	111	173	183	155	240	110	115	147	97
	8	135	130	152	130	128	136	125	130	110	171	174	138	156	94	92	155	138
Philadelphia	All	105	103	106	111	100	99	111	97	104	125	90	97	111	123	86	105	109
	10	94	95	93	103	85	88	110	88	99	106	74	82	110	117	79	82	95
	11	122	119	127	128	115	113	134	111	130	142	108	116	128	139	110	105	131
	12	118	112	117	135	109	105	125	106	109	138	104	119	132	152	94	118	115
	13	146	134	146	164	141	129	144	129	137	181	122	134	166	192	130	142	152
	14	125	126	128	132	115	125	132	120	115	152	118	122	131	144	98	121	126
	15	85	85	83	81	93	84	89	81	87	101	60	68	86	88	61	124	94
	16	69	73	71	64	68	71	77	72	74	82	56	58	63	71	51	69	84
All Cities	17	79	78	87	78	74	81	79	74	81	98	82	76	75	83	65	80	77
		101	103	105	100	96	106	104	100	94	121	100	94	107	100	81	105	101

CITY	Site	Annual Sumr	SEASON				MONTH											
			Fall	Wntr	Sprng	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
Cincinnati	Mean	75	81	74	72	73	83	76	85	78	75	67	64	72	78	70	59	90
	30	93	104	92	92	85	115	89	109	97	94	84	83	90	102	83	73	99
	31	72	76	73	69	72	77	69	81	79	76	65	61	71	75	73	57	85
	32	85	91	88	79	84	93	87	93	99	88	79	71	80	84	75	64	112
	33	49	55	41	47	53	48	60	56	38	44	42	43	48	50	51	41	65
Los Angeles	Mean	100	111	113	80	95	114	115	105	73	119	146	80	84	77	70	133	83
	1	109	118	137	85	96	124	120	109	89	139	183	107	76	73	78	132	76
	2	92	93	115	70	91	88	99	91	85	127	134	61	62	86	72	128	73
	3	96	121	117	72	75	134	122	108	77	115	158	60	86	70	60	88	78
	4	95	119	94	78	90	130	119	107	60	100	123	55	69	109	55	132	82
	5	92	118	101	58	92	121	122	111	68	98	136	73	70	32	65	124	87
	6	86	84	81	78	100	89	85	78	44	94	104	63	104	66	50	143	108
	7	114	118	128	104	105	109	130	115	81	132	171	109	101	101	100	139	76
	8	116	120	131	98	116	117	125	119	82	150	160	110	106	78	83	175	89
Philadelphia	Mean	100	91	101	114	94	82	107	84	102	111	91	108	115	120	81	91	110
	10	94	89	89	114	86	75	109	82	94	99	72	97	122	122	82	77	100
	11	118	105	118	133	116	96	125	94	128	123	102	135	129	134	113	90	143
	12	114	100	111	138	105	89	118	94	113	123	97	129	137	149	90	103	121
	13	138	115	142	163	132	103	132	109	136	170	121	138	167	186	132	118	148
	14	115	109	116	134	100	99	126	102	110	123	115	130	135	138	84	105	112
	15	77	70	79	81	79	65	85	61	82	87	68	78	83	82	47	96	96
	16	64	65	66	67	60	58	76	62	70	71	57	68	67	66	43	60	77
	17	81	73	80	86	73	63	82	69	80	94	94	97	87	84	86	77	82
All Cities		92	94	96	89	88	93	99	91	84	102	101	84	91	92	74	94	94

TABLE 7
ANNUAL, SEASONAL, AND MONTHLY MEAN SUSPENDED PARTICULATE CONCENTRATIONS ON
WEEKDAYS IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	Site	Annual	SEASON				MONTH											
			Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cincinnati	All	86	91	88	77	90	95	88	90	78	113	72	75	80	76	76	90	104
	30	103	107	107	93	104	107	105	109	91	140	91	90	94	96	91	103	119
	31	81	82	85	71	85	85	83	79	79	110	65	68	72	74	75	90	100
	32	104	108	106	90	112	113	101	110	93	143	82	90	96	83	89	122	121
	33	58	66	53	54	60	75	61	61	50	60	48	53	56	53	51	54	73
Los Angeles	All	131	128	145	138	111	140	121	124	120	178	136	141	161	112	93	136	105
	1	137	131	161	139	118	139	126	128	135	197	151	154	179	85	103	152	100
	2	120	105	146	138	90	117	96	101	117	183	138	178	139	97	80	113	76
	3	129	140	138	135	104	162	130	127	129	178	108	128	147	129	92	136	84
	4	122	143	116	120	109	154	133	144	105	138	105	113	129	118	90	145	91
	5	119	134	131	108	105	149	128	125	116	169	107	102	120	102	90	138	87
	6	106	103	110	114	97	113	89	105	89	137	105	103	99	179	65	109	117
	7	159	134	180	194	130	137	140	127	130	217	193	186	278	117	124	115	111
	8	152	138	176	157	137	151	124	138	136	210	183	167	197	108	99	138	174
Philadelphia	All	109	112	111	108	106	112	116	106	106	138	90	89	108	126	89	119	109
	10	94	100	97	95	85	97	111	92	102	113	75	73	100	113	76	88	92
	11	126	130	134	124	117	126	143	123	132	159	112	103	128	143	107	120	122
	12	122	121	122	132	114	117	133	114	106	151	109	112	129	155	98	131	112
	13	153	148	150	165	150	148	156	142	137	191	123	132	165	198	129	165	155
	14	134	137	139	131	127	142	137	132	119	179	120	116	128	149	108	136	136
	15	92	95	86	81	106	97	93	94	90	114	55	61	89	94	73	150	94
	16	73	79	76	63	74	81	78	78	78	94	55	50	59	78	57	77	90
	17	78	81	84	72	75	91	76	77	81	101	71	69	67	80	68	82	74
		109	110	114	108	102	116	108	107	101	143	99	102	116	105	86	115	106
All Cities																		

Particulate levels at rural sites in Cincinnati and Philadelphia were lower than at other sites. This was not true in Los Angeles, probably because its rural, industrial, and downtown areas are less well defined (Figures 1, 2, and 3, and Table 5).

The average concentration of particulates in all weekday samples was 15 percent higher than that in all weekend samples in Cincinnati, 30 percent higher in Los Angeles, and 10 percent higher in Philadelphia (Tables 6 and 7). The greatest weekday-weekend difference over one season occurred in winter in Los Angeles where the average of all weekday samples was about 75 percent above that for weekends. In that same season, the average value of all weekday samples was 7 percent higher than the weekend average in Cincinnati, and 5 percent lower in Philadelphia.

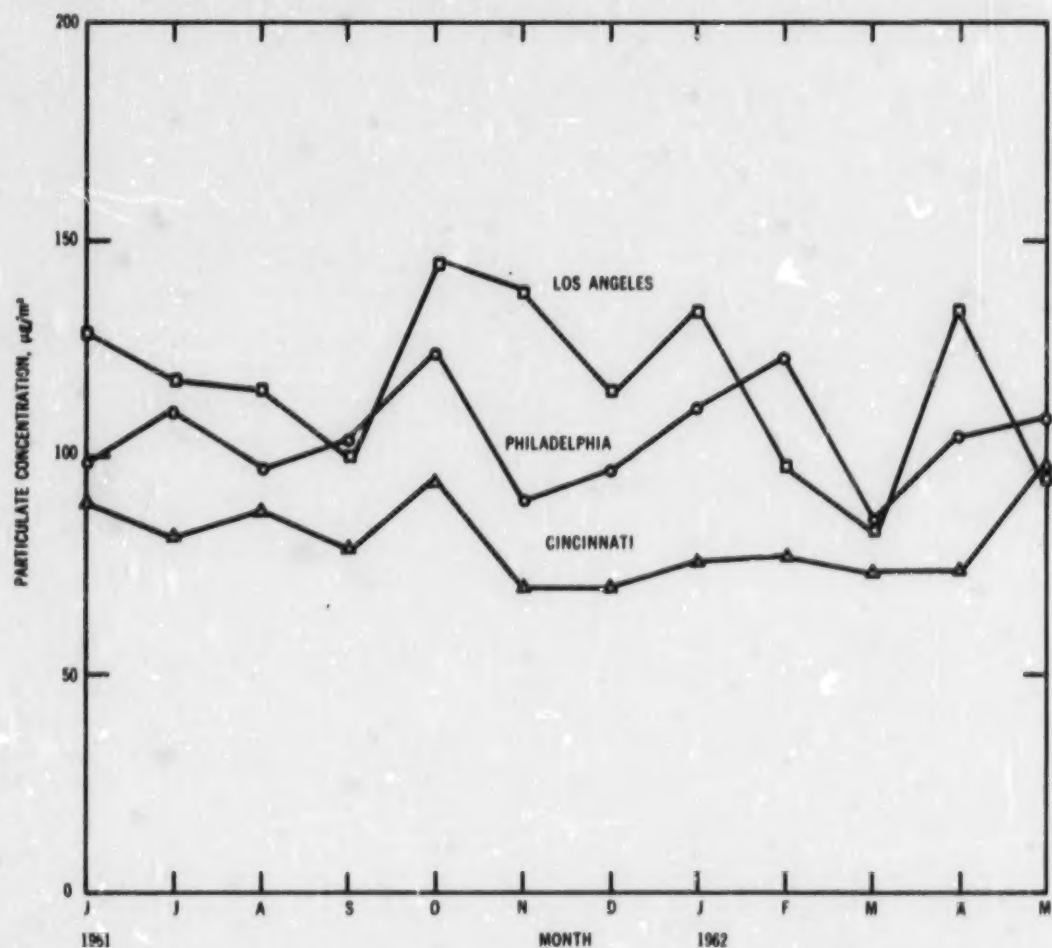


FIGURE 6
MONTHLY MEAN PARTICULATE CONCENTRATIONS
AT ALL STATIONS IN
CINCINNATI, LOS ANGELES, AND PHILADELPHIA

Very often, mean monthly concentrations for weekend samples were higher than those for weekdays. For example, in Philadelphia during December and January and in Los Angeles in November, mean monthly concentrations on weekdays were lower than on weekends at most of the sampling sites.

Lead: Data on atmospheric lead are presented in Tables 8 through 18 and Figures 7 through 16.

The distributions of lead concentration by sites for each city are shown in Figures 7 through 9. The annual average concentration of lead at downtown and industrial sites in Cincinnati was about 2 micrograms per cubic meter. At the suburban Cincinnati site the value was approximately 1 microgram per cubic meter. The corresponding values in downtown and suburban Philadelphia were 3 and 1. In Los Angeles the values were 3 and 2, and at no sites did values average as low as 1 microgram per cubic meter. This again was probably due to the absence of well-defined suburban, downtown, and industrial areas in this city.

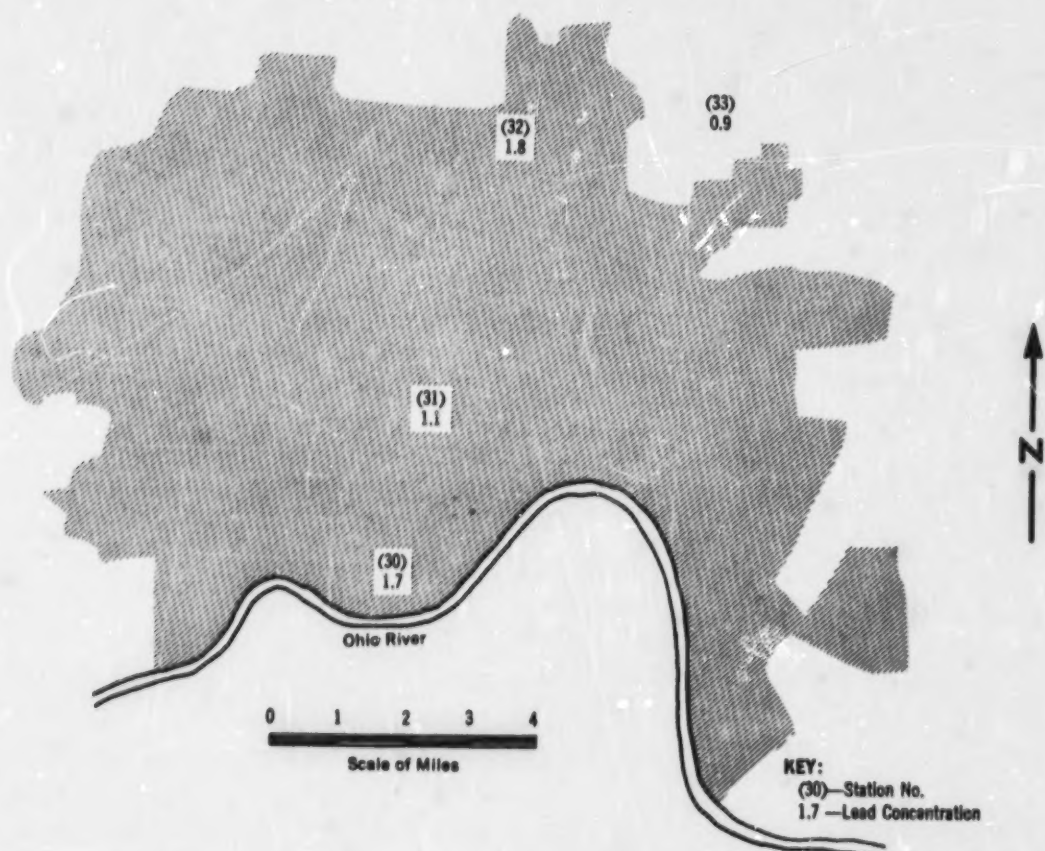


FIGURE 7
MEAN ANNUAL CONCENTRATIONS OF LEAD
IN CINCINNATI AREA BY SITE
(In micrograms per cubic meter of air)

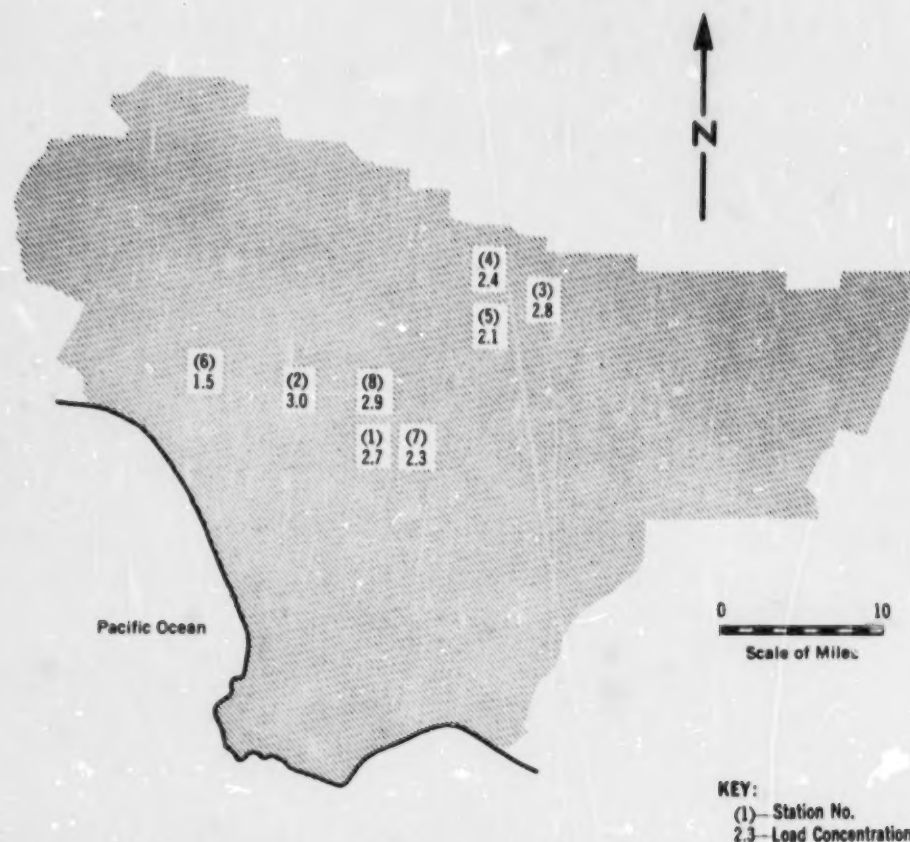


FIGURE 8
MEAN ANNUAL CONCENTRATIONS OF LEAD
IN LOS ANGELES AREA BY SITE
 (In micrograms per cubic meter of air)

The average concentration of lead for all samples collected over the year was 1.4 micrograms per cubic meter in Cincinnati, 2.5 in Los Angeles, and 1.6 in Philadelphia (Table 8).

Fall and winter were the seasons of highest lead concentrations in all three cities. The highest seasonal concentration at any station was 2.4 micrograms per cubic meter in Cincinnati, 4.1 in Los Angeles, and 3.8 in Philadelphia (Table 8). The highest concentration for all samples during the fall season in Cincinnati was 30 percent greater than that for summer. In Los Angeles, the average for all winter samples was 63 percent higher than for summer. In Philadelphia, the average value for both the fall and winter seasons was 35 percent greater than the summer seasonal average.

The highest monthly concentrations for all samples in each city were 2.1 micrograms per cubic meter in Cincinnati (October), 3.9 in Los Angeles (December), and 2.3 in Philadelphia (October) (Table 8 and

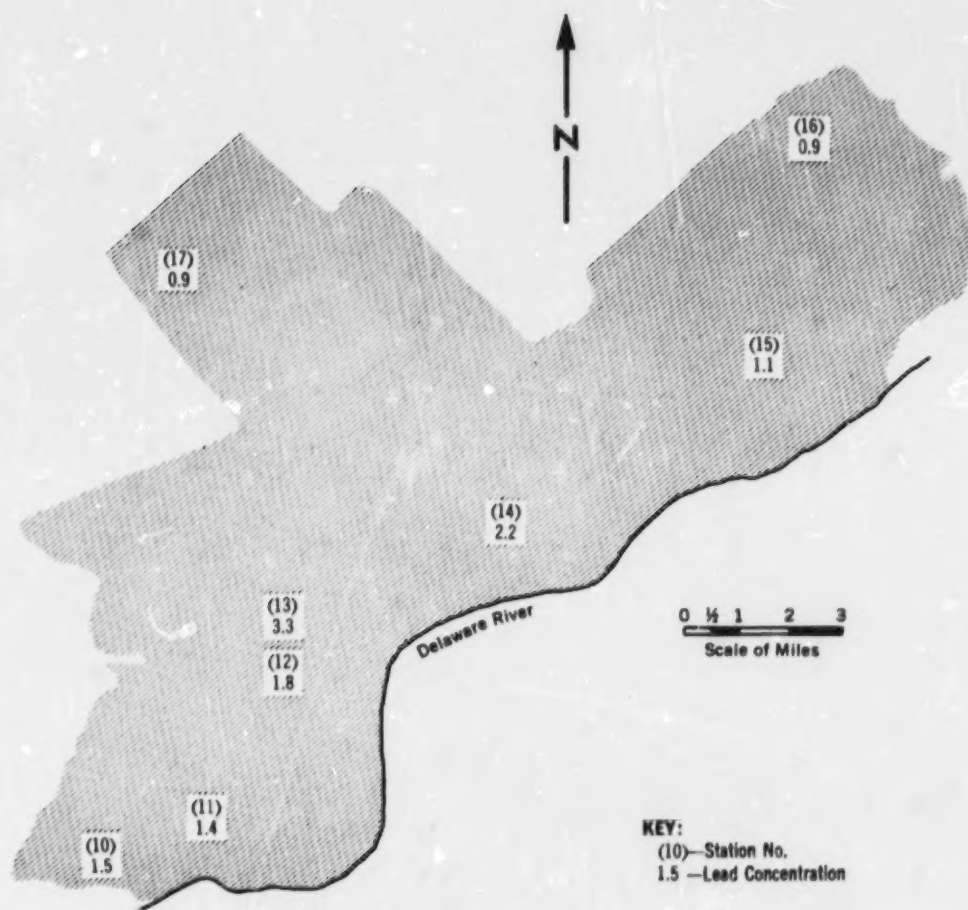


FIGURE 9
MEAN ANNUAL CONCENTRATIONS OF LEAD
IN PHILADELPHIA AREA BY SITE
(In micrograms per cubic meter of air)

Figure 10). Highest monthly concentration for any one site was 3.1 micrograms per cubic meter in Cincinnati, 6.4 in Los Angeles, and 4.4 in Philadelphia (Table 8).

The highest concentrations of lead in individual samples were 6.4 micrograms per cubic meter in Cincinnati, 11.4 in Los Angeles, and 7.6 in Philadelphia. The frequency distribution of individual airborne lead samples is shown in Table 9.

In Los Angeles, the average of all weekday samples was 23 percent higher than the average of all weekend samples (Tables 10 and 11). In Philadelphia and Cincinnati, annual weekday values were similar to weekend values. At individual sites in all three cities, however, the monthly lead concentrations were often lower on weekdays than on weekends.

TABLE 8

ANNUAL, SEASONAL, AND MONTHLY MEAN CONCENTRATIONS OF LEAD IN CINCINNATI,
LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	Site	SEASON				MONTH												
		Annual	Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cincinnati	All	1.4	1.3	1.7	1.3	1.3	1.4	1.1	1.6	1.5	2.1	1.4	1.4	1.2	1.2	0.9	1.2	1.7
	30	1.7	1.6	2.0	1.7	1.6	1.5	1.2	2.1	1.9	2.2	1.9	1.8	1.5	1.7	1.3	1.6	2.0
	31	1.1	1.1	1.5	1.0	1.0	1.1	0.9	1.4	1.3	2.0	1.1	1.0	1.0	0.9	0.7	0.9	1.3
	32	1.8	1.5	2.4	1.5	1.7	1.4	1.3	1.9	2.1	3.1	2.0	1.8	1.3	1.3	1.2	1.6	2.2
	33	0.9	1.1	0.8	1.0	0.8	1.4	0.9	1.0	0.7	0.9	0.7	1.1	1.0	0.8	0.5	0.7	1.1
Los Angeles	All	2.5	1.9	2.8	3.1	2.1	1.7	1.9	2.2	2.2	2.7	3.5	3.9	3.2	2.2	2.0	2.4	1.8
	1	2.7	2.0	3.0	3.6	2.1	2.1	1.8	2.1	2.2	3.0	3.8	4.8	3.9	2.0	2.3	2.6	1.3
	2	3.0	2.0	4.1	4.0	2.0	1.5	2.2	2.4	3.0	3.7	5.7	6.4	3.0	2.5	1.2	2.7	2.2
	3	2.8	2.3	3.4	3.7	1.7	2.2	2.0	2.7	3.0	3.7	3.6	4.6	4.0	2.5	1.8	1.7	1.5
	4	2.4	2.4	2.3	2.6	2.3	2.1	2.3	2.8	2.0	2.2	2.7	2.7	2.3	2.7	1.9	2.7	2.4
	5	2.1	2.0	1.9	2.1	2.2	1.7	1.9	2.4	1.6	2.1	2.1	2.6	2.2	1.6	2.1	2.5	2.0
	6	1.5	1.2	1.6	1.9	1.5	1.0	1.1	1.4	1.4	1.8	1.7	2.2	2.0	1.5	0.9	2.0	1.5
	7	2.3	1.4	2.5	3.3	2.0	1.2	1.5	1.5	1.9	2.5	3.1	3.9	3.7	2.4	2.4	2.2	1.5
	8	2.9	2.2	3.3	3.6	2.6	2.1	2.0	2.5	2.8	2.3	4.9	4.0	4.3	2.5	3.1	3.1	1.7
Philadelphia	All	1.6	1.4	1.9	1.9	1.4	1.3	1.4	1.5	1.6	2.3	1.7	2.1	1.8	1.9	1.2	1.4	1.5
	10	1.5	1.4	1.7	1.8	1.2	1.1	1.5	1.5	1.6	2.1	1.4	1.9	1.6	1.9	1.0	1.1	1.4
	11	1.4	1.2	1.6	1.7	1.1	1.1	1.3	1.2	1.5	2.0	1.4	1.8	1.6	1.8	1.1	1.1	1.2
	12	1.8	1.3	1.9	2.3	1.6	1.2	1.4	1.4	1.6	2.2	2.0	2.5	2.1	2.4	1.5	1.6	1.6
	13	3.3	2.7	3.8	3.8	2.9	2.4	2.9	2.9	3.4	4.4	3.5	4.2	3.6	3.7	2.8	2.7	3.3
	14	2.2	1.8	2.3	2.6	2.0	1.7	1.8	1.9	1.8	2.8	2.3	2.8	2.3	2.6	1.8	2.1	2.1
	15	1.1	1.0	1.4	1.3	0.9	0.9	0.9	1.1	1.1	2.0	1.1	1.4	1.5	1.1	0.6	1.2	0.9
	16	0.9	0.8	1.0	1.0	0.7	0.7	0.8	0.9	1.0	1.3	0.8	1.1	0.9	0.9	0.6	0.8	0.8
	17	0.9	0.9	1.1	0.9	0.6	1.1	0.8	0.9	0.9	1.3	1.0	1.0	0.8	0.9	0.5	0.7	0.7
All Cities		1.8	1.6	2.1	2.1	1.6	1.5	1.5	1.8	1.8	2.3	2.2	2.5	2.1	1.8	1.4	1.7	1.6

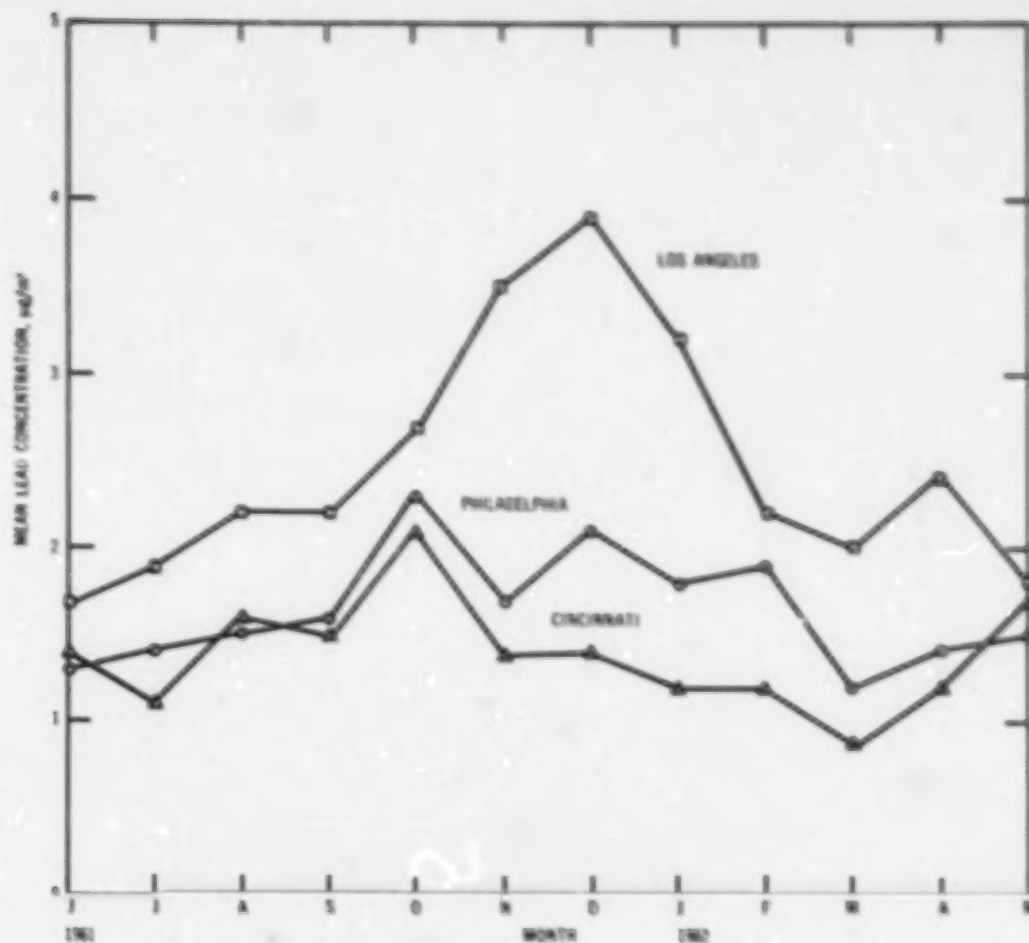


FIGURE 10
MEAN MONTHLY CONCENTRATIONS OF LEAD
AT ALL SITES IN
CINCINNATI, LOS ANGELES, AND PHILADELPHIA

Lead in particulates: Correlations between lead and suspended particulates at the sites in Cincinnati and Philadelphia for the study year were about 0.7; variance in concentrations of suspended particulates thus explains about half of the variation in lead concentrations. In Los Angeles, the correlation was about 0.6, which explains about one-third of the variance.

The average content of lead in particulate matter for all samples was 1.7 percent in Cincinnati, 2.3 in Los Angeles, and 1.5 in Philadelphia (Table 12). The mean percentage of lead was the same on weekends and weekdays in the three cities. (Not shown in any Tables included in this report.) The percentage of lead averaged for individual sites by month ranged from 0.9 to 2.5 in Cincinnati, 0.9 to 5.3 in Los Angeles, and 0.9 to 3.1 in Philadelphia (Table 12).

TABLE 9
FREQUENCY DISTRIBUTIONS OF AIRBORNE LEAD CONCENTRATIONS
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	SEASON*	CNT	MIN	10	20	30	40	50	60	70	80	90	Max.	Arith. Mean	Geom. Mean	Std. Dev.
Cincinnati	WINTER	149	.3	.6	.7	.9	1.0	1.1	1.2	1.4	1.7	2.1	6.4	1.3	1.2	1.66
	SPRING	153	.3	.5	.6	.7	.9	1.1	1.2	1.5	1.8	2.5	5.9	1.3	1.1	1.83
	SUMMER	160	.3	.6	.7	.8	1.0	1.2	1.4	1.5	1.8	2.3	3.8	1.4	1.2	1.65
	AUTUMN	154	.4	.6	.8	.9	1.2	1.3	1.6	2.0	2.5	3.3	5.9	1.7	1.4	1.87
	ANNUAL	616	.3	.5	.7	.8	1.0	1.2	1.3	1.5	1.9	2.6	6.4	1.4	1.2	1.77
Los Angeles	WINTER	275	.4	1.1	1.6	1.9	2.3	2.7	3.3	4.2	5.5	7.3	9.5	3.5	2.8	1.99
	SPRING	299	.2	.9	1.2	1.3	1.6	1.9	2.2	2.6	2.9	3.5	6.7	2.1	1.9	1.75
	SUMMER	409	.1	1.0	1.3	1.5	1.7	1.9	2.1	2.4	2.7	3.1	5.5	2.0	1.8	1.87
	AUTUMN	264	.4	1.0	1.5	1.9	2.1	2.5	2.9	3.4	4.1	5.3	11.4	2.9	2.5	1.95
	ANNUAL	1247	.1	1.0	1.3	1.6	1.8	2.1	2.4	2.8	3.4	4.5	11.4	2.6	2.2	1.87
Philadelphia	WINTER	309	.2	.6	.9	1.1	1.3	1.5	1.8	2.3	2.9	3.5	7.5	1.9	1.6	1.92
	SPRING	299	.2	.5	.6	.8	1.0	1.2	1.4	1.6	2.0	2.8	5.2	1.4	1.2	1.87
	SUMMER	350	.1	.6	.8	.9	1.1	1.2	1.4	1.6	2.0	2.5	4.7	1.3	1.3	1.68
	AUTUMN	310	.3	.7	.9	1.2	1.3	1.5	1.8	2.2	2.8	3.5	8.9	1.9	1.6	1.83
	ANNUAL	1268	.1	.6	.8	1.0	1.2	1.3	1.6	1.9	2.4	3.1	7.5	1.7	1.4	1.87

*WINTER: December 1, 1961 thru February 28, 1962
 SPRING: March 1, 1962 thru May 31, 1962
 SUMMER: June 1, 1961 thru August 31, 1961
 AUTUMN: September 1, 1961 thru November 30, 1961

TABLE 10

ANNUAL, SEASONAL, AND MONTHLY MEAN CONCENTRATIONS OF LEAD ON WEEKENDS
IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	Site	SEASON					MONTH											
		Annual	Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cincinnati	All	1.3	1.3	1.6	1.3	1.1	1.5	0.9	1.6	1.7	1.7	1.5	1.3	1.1	1.4	0.9	0.8	1.7
	30	1.7	1.8	1.8	1.7	1.4	2.2	1.0	2.3	2.0	1.8	1.7	1.6	1.4	2.2	1.1	1.3	1.9
	31	1.2	1.2	1.6	1.1	0.9	1.4	0.7	1.5	1.5	1.8	1.4	1.0	1.0	1.2	0.7	0.6	1.3
	32	1.7	1.4	2.5	1.5	1.5	1.4	1.1	1.7	2.4	2.6	2.4	1.7	1.3	1.5	1.2	1.0	2.4
	33	0.7	0.9	0.7	0.7	0.6	0.9	0.7	1.0	0.8	0.7	0.6	0.7	0.8	0.7	0.5	0.4	1.0
Los Angeles	All	2.2	1.8	2.5	2.4	2.0	1.5	1.7	2.3	2.0	2.2	3.2	3.0	2.3	2.1	1.9	2.6	1.5
	1	2.5	2.0	3.1	3.0	2.0	2.1	1.7	2.3	2.2	2.9	4.2	4.7	2.5	1.7	2.5	2.5	0.9
	2	2.5	1.9	3.7	2.7	2.0	1.1	1.8	2.7	2.9	3.2	4.9	3.7	1.3	2.5	1.0	3.2	1.8
	3	2.4	2.3	2.9	2.9	1.6	2.2	2.0	2.7	2.5	2.8	3.5	3.5	3.2	2.1	1.9	1.6	1.4
	4	2.0	2.2	1.7	2.2	2.0	1.7	2.1	2.7	1.5	1.4	2.2	2.0	1.9	2.8	1.4	2.5	2.0
	5	1.9	1.9	1.7	1.7	2.2	1.6	1.7	2.4	1.4	1.6	2.0	1.9	2.3	1.0	2.1	2.3	2.1
	6	1.4	1.2	1.3	1.7	1.4	0.8	1.1	1.7	0.9	1.4	1.7	1.6	2.1	1.5	0.9	1.9	1.3
	7	2.0	1.3	2.4	2.4	1.8	0.9	1.7	1.4	1.9	2.1	3.1	3.4	1.6	2.3	2.4	2.2	0.9
	8	2.7	2.0	3.0	2.8	3.0	1.5	1.7	2.7	2.5	2.5	4.1	3.0	3.0	2.5	3.3	4.2	1.4
Philadelphia	All	1.6	1.2	1.8	2.0	1.3	1.0	1.3	1.4	1.6	2.1	1.6	2.3	2.0	1.8	1.2	1.1	1.5
	10	1.5	1.3	1.6	2.0	1.1	0.9	1.4	1.6	1.6	2.0	1.3	2.3	1.9	1.8	0.9	0.9	1.6
	11	1.4	1.1	1.5	1.9	1.1	1.0	1.2	1.2	1.4	1.9	1.3	2.2	1.9	1.6	1.0	0.8	1.4
	12	1.7	1.2	1.8	2.3	1.5	1.0	1.2	1.4	1.6	2.0	1.7	2.6	2.3	2.1	1.5	1.2	1.8
	13	3.1	2.3	3.5	3.8	2.8	1.7	2.7	2.5	3.2	4.0	3.2	4.2	3.9	3.4	2.8	2.2	3.3
	14	2.1	1.5	2.2	2.9	1.7	1.3	1.6	1.6	1.7	2.5	2.3	3.4	2.7	2.5	1.6	1.6	1.9
	15	1.1	0.9	1.4	1.3	0.8	0.8	0.8	1.0	1.0	1.8	1.3	1.5	1.5	1.0	0.6	0.9	0.9
	16	0.8	0.8	1.0	1.0	0.6	0.7	0.8	0.8	1.0	1.1	0.8	1.3	1.1	0.7	0.5	0.6	0.7
	17	0.9	0.8	1.1	1.0	0.5	0.8	0.7	0.9	0.9	1.3	1.1	1.1	0.9	1.0	0.4	0.5	0.7
All Cities																		
		1.7	1.5	2.0	1.9	1.5	1.3	1.3	1.8	1.7	2.0	2.1	2.2	1.8	1.7	1.3	1.5	1.6

TABLE 11
ANNUAL, SEASONAL, AND MONTHLY MEAN CONCENTRATIONS OF LEAD ON WEEKDAYS
IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962
(IN MICROGRAMS PER CUBIC METER OF AIR)

CITY	Site	SEASON					MONTH												
		Annual	Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
Cincinnati	All	1.4	1.4	1.7	1.3	1.4	1.3	1.2	1.5	1.4	2.4	1.4	1.6	1.3	1.1	1.0	1.6	1.6	
	30	1.8	1.5	2.1	1.6	1.8	1.1	1.4	1.9	1.8	2.6	2.0	1.9	1.6	1.4	1.4	2.0	2.0	
	31	1.1	1.1	1.4	1.0	1.0	1.0	1.0	1.2	1.2	2.2	0.9	1.1	1.0	0.8	0.7	1.1	1.3	
	32	1.8	1.6	2.4	1.5	1.8	1.4	1.4	1.9	1.8	3.5	1.8	2.0	1.4	1.1	1.2	2.3	2.0	
	33	1.1	1.3	0.8	1.2	0.9	1.8	1.1	1.0	0.6	1.1	0.8	1.5	1.2	1.0	0.5	0.9	1.2	
Los Angeles	All	2.7	2.0	3.1	3.5	2.1	1.9	2.0	2.2	2.4	3.2	3.5	4.6	3.6	2.3	2.0	2.3	1.9	
	1	2.8	2.0	3.0	3.9	2.2	2.0	2.0	2.0	2.3	3.1	3.6	4.9	4.6	2.1	2.3	2.7	1.5	
	2	3.4	2.1	4.5	4.9	2.1	1.7	2.4	2.3	3.1	4.4	6.0	8.4	3.9	2.5	1.4	2.3	2.5	
	3	3.0	2.3	3.9	4.1	1.6	2.2	2.1	2.7	3.4	4.8	3.6	5.1	4.5	2.8	1.7	1.7	1.5	
	4	2.7	2.5	2.8	2.9	2.5	2.3	2.4	2.9	2.2	3.2	2.9	3.6	2.5	2.6	2.2	2.8	2.6	
	5	2.3	2.1	2.4	2.4	2.2	1.8	2.1	2.4	1.8	3.1	2.2	3.1	2.1	1.9	2.1	2.7	1.9	
	6	1.6	1.1	1.8	2.0	1.5	1.1	1.0	1.3	1.6	2.2	1.6	2.6	1.8	1.8	0.9	2.0	1.6	
	7	2.5	1.4	2.7	3.6	2.1	1.4	1.4	1.5	1.9	3.0	3.1	4.2	4.3	2.4	2.3	2.1	1.9	
	8	3.1	2.3	3.4	4.2	2.4	2.5	2.2	2.3	3.1	1.8	5.3	4.9	5.3	2.4	2.9	2.2	2.0	
Philadelphia	All	1.7	1.5	1.9	1.9	1.5	1.5	1.6	1.6	1.6	2.5	1.7	1.9	1.6	2.1	1.3	1.7	1.5	
	10	1.5	1.5	1.8	1.7	1.1	1.3	1.6	1.5	1.6	2.3	1.4	1.6	1.4	2.0	1.0	1.3	1.1	
	11	1.4	1.3	1.7	1.6	1.2	1.2	1.4	1.3	1.5	2.1	1.4	1.6	1.3	2.0	1.1	1.3	1.1	
	12	1.9	1.4	2.1	2.3	1.6	1.3	1.6	1.4	1.5	2.5	2.2	2.4	1.9	2.6	1.5	1.9	1.5	
	13	3.5	3.1	4.0	3.9	3.1	2.9	3.1	3.2	3.5	4.8	3.6	4.2	3.4	4.0	2.7	3.2	3.4	
	14	2.3	2.1	2.3	2.4	2.3	2.0	2.0	2.2	1.8	3.0	2.2	2.4	2.0	2.7	1.9	2.6	2.3	
	15	1.2	1.1	1.4	1.3	1.0	1.0	1.1	1.2	1.1	2.2	0.9	1.2	1.5	1.2	0.6	1.4	0.9	
	16	0.9	0.9	1.1	0.9	0.9	0.8	0.8	1.0	0.9	1.6	0.8	0.9	0.7	1.0	0.7	1.0	0.9	
	17	0.9	1.0	1.0	0.8	0.7	1.4	0.8	0.9	0.9	1.3	0.9	0.8	0.7	0.9	0.6	0.8	0.7	
			1.9	1.6	2.2	2.2	1.6	1.6	1.6	1.8	1.8	2.7	2.2	2.7	2.2	1.8	1.4	1.9	1.7

TABLE 12
ANNUAL, SEASONAL, AND MONTHLY PERCENTAGE OF LEAD IN PARTICULATE MATTER
IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA—JUNE 1961 THROUGH MAY 1962

CITY	Site	SEASON					MONTH											
		Annual	Sumr	Fall	Wntr	Spring	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cincinnati	All	1.7	1.5	2.0	1.7	1.5	1.6	1.3	1.8	1.9	2.0	2.0	2.0	1.7	1.5	1.2	1.5	1.7
	30	1.7	1.4	2.0	1.8	1.7	1.3	1.2	1.8	2.0	1.8	2.1	2.0	1.7	1.7	1.5	1.8	1.8
	31	1.4	1.4	1.8	1.4	1.2	1.4	1.1	1.6	1.7	2.0	1.7	1.5	1.4	1.2	0.9	1.2	1.4
	32	1.8	1.5	2.4	1.7	1.7	1.3	1.3	1.8	2.2	2.5	2.5	2.1	1.5	1.4	1.5	1.7	1.9
	33	1.7	1.9	1.7	2.0	1.3	2.3	1.5	1.8	1.6	1.7	1.7	2.4	2.0	1.7	1.0	1.4	1.6
Los Angeles	All	2.3	1.6	2.3	3.2	2.2	1.3	1.6	1.9	2.3	1.9	2.6	3.7	2.9	3.0	2.6	1.9	2.1
	1	2.2	1.6	2.2	3.1	2.0	1.6	1.5	1.7	2.1	1.9	2.5	3.9	2.8	2.7	2.6	1.7	1.6
	2	2.9	2.0	3.3	4.1	2.3	1.4	2.2	2.5	3.0	2.5	4.3	5.3	3.5	3.5	1.8	2.3	2.9
	3	2.8	1.8	2.9	4.3	2.1	1.5	1.6	2.3	2.9	2.5	3.3	5.1	3.9	3.9	2.7	1.6	1.9
	4	2.4	1.8	2.1	3.2	2.4	1.4	1.8	2.3	2.2	1.9	2.1	3.6	2.9	3.0	2.6	1.9	2.7
	5	2.1	1.6	1.9	2.8	2.4	1.3	1.5	2.0	1.8	1.7	2.1	3.1	2.6	2.6	2.9	1.9	2.3
	6	1.8	1.2	1.8	2.4	1.8	1.0	1.1	1.6	2.0	1.6	1.8	2.6	2.3	2.2	1.7	1.9	1.7
	7	1.7	1.1	1.7	2.3	1.8	0.9	1.1	1.2	1.8	1.5	1.9	2.7	1.8	2.5	2.2	1.5	1.6
	8	2.5	1.7	2.4	3.2	2.6	1.5	1.6	1.9	2.7	1.4	3.1	3.2	3.2	3.3	4.0	2.0	1.7
Philadelphia	All	1.5	1.4	1.7	1.7	1.4	1.3	1.2	1.5	1.6	1.8	1.8	2.0	1.6	1.5	1.4	1.3	1.4
	10	1.6	1.5	1.9	1.8	1.4	1.4	1.4	1.8	1.7	2.0	1.9	2.2	1.5	1.6	1.2	1.4	1.5
	11	1.2	1.1	1.2	1.4	1.0	1.0	1.0	1.2	1.1	1.4	1.2	1.6	1.2	1.3	1.0	1.0	1.0
	12	1.5	1.2	1.7	1.7	1.5	1.2	1.1	1.4	1.5	1.7	2.0	2.1	1.5	1.5	1.6	1.4	1.4
	13	2.3	2.1	2.7	2.4	2.1	1.9	2.0	2.3	2.6	2.6	2.8	3.1	2.2	1.9	2.1	1.9	2.3
	14	1.7	1.4	1.8	1.9	1.7	1.4	1.3	1.6	1.6	1.9	1.9	2.2	1.8	1.7	1.8	1.7	1.7
	15	1.4	1.2	1.7	1.7	1.1	1.2	1.1	1.4	1.4	2.0	1.7	2.0	1.7	1.3	1.1	1.1	1.0
	16	1.3	1.1	1.5	1.5	1.1	1.1	1.0	1.3	1.4	1.6	1.5	1.8	1.4	1.2	1.2	1.2	1.0
	17	1.2	1.2	1.3	1.2	0.9	1.5	1.0	1.2	1.2	1.4	1.2	1.3	1.2	1.2	0.9	0.9	1.0
		1.8	1.5	2.0	2.2	1.7	1.4	1.4	1.7	1.9	1.9	2.1	2.6	2.0	2.0	1.7	1.6	1.7

In the fall, the percentage of lead in samples in Cincinnati was one-third higher than in summer, and in Philadelphia it was one-fourth higher (Table 12 and Figure 11). The greatest seasonal difference occurred in Los Angeles, where the winter percentage of all samples was one-half higher than the summer value. The factors responsible for these seasonal differences are not clear. The average summer values for suspended particulates differ very little from the fall and winter values. Lead values, however, are considerably lower in summer than in fall and winter in all three cities.

Diurnal distribution of lead: Lead concentrations in all three cities peaked in the morning around 7 A.M. (Tables 13, 14, and 15, and Figures 12, 13, and 14). Secondary peaks occurred in the afternoon in Philadelphia and Los Angeles. In Cincinnati, the secondary peak was not as pronounced and occurred in the early evening. These diurnal variations reflect variations in both source strength and meteorological conditions.

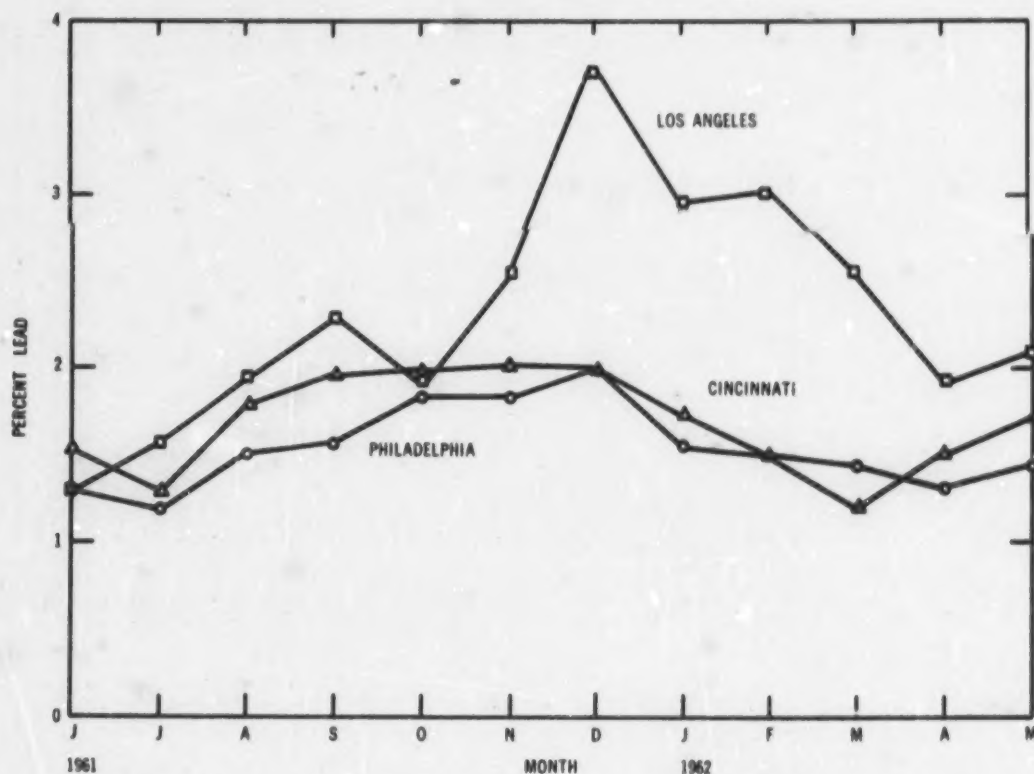


FIGURE 11
MONTHLY MEAN PERCENT OF LEAD IN PARTICULATE
MATTER AT ALL STATIONS IN
CINCINNATI, LOS ANGELES, AND PHILADELPHIA

TABLE 13
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN
CINCINNATI EXPRESSED AS THE RATIO OF DIURNAL
VALUES TO THE YEARLY MEAN SAMPLING INTERVAL

Site	Season	Mean	23:00	03:00	07:00	11:00	15:00	19:00
			to 03:00	to 07:00	to 11:00	to 15:00	to 19:00	to 23:00
All	Annual	1.0	1.3	1.1	1.4	0.8	0.9	1.0
	Summer	1.1	1.4	1.4	1.4	0.6	0.8	1.0
	Fall	1.3	1.3	1.3	1.8	0.8	1.0	1.4
	Winter	0.9	0.9	0.8	1.1	1.0	1.0	1.0
	Spring	0.9	1.3	1.0	1.1	0.6	0.6	0.9
30	Annual	1.4	1.6	1.5	2.0	1.1	1.3	1.3
	Summer	1.5	1.9	2.0	2.0	0.9	1.1	1.3
	Fall	1.5	1.6	1.5	2.8	0.9	1.1	1.4
	Winter	1.3	1.0	1.0	1.5	1.5	1.5	1.3
	Spring	1.4	1.9	1.4	1.9	1.0	1.0	1.3
31	Annual	1.1	1.5	1.3	1.4	0.6	0.8	1.0
	Summer	1.3	1.8	1.8	1.5	0.5	0.5	1.1
	Fall	1.3	1.9	1.6	1.8	0.6	0.8	1.1
	Winter	1.0	1.1	0.9	1.1	1.0	0.9	1.0
	Spring	0.9	1.3	0.9	1.1	0.5	0.6	0.9
32	Annual	1.2	1.4	1.0	1.3	0.8	1.0	1.4
	Summer	1.2	1.5	1.3	1.3	0.6	1.1	1.3
	Fall	1.6	2.3	1.5	1.9	0.9	1.3	2.3
	Winter	0.8	0.8	0.5	0.9	0.6	1.0	0.9
	Spring	0.9	1.1	0.9	0.9	0.6	0.6	1.0
33	Annual	0.5	0.5	0.5	0.8	0.5	0.5	0.5
	Summer	0.5	0.5	0.5	0.8	0.3	0.4	0.4
	Fall	0.5	0.5	0.4	0.6	0.5	0.6	0.6
	Winter	0.6	0.5	0.5	1.0	0.6	0.6	0.6
	Spring	0.5	0.6	0.6	0.6	0.4	0.3	0.4

TABLE 14
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN
LOS ANGELES EXPRESSED AS THE RATIO OF DIURNAL
VALUES TO THE YEARLY MEAN SAMPLING INTERVAL

Site	Season	Mean	23:00	03:00	07:00	11:00	15:00	19:00
			to 03:00	to 07:00	to 11:00	to 15:00	to 19:00	to 23:00
All	Annual	1.0	1.0	1.1	1.2	0.7	0.8	1.1
	Summer	0.7	0.6	0.6	1.1	0.7	0.5	0.5
	Fall	1.2	1.2	1.4	1.3	0.7	1.0	1.5
	Winter	1.4	1.4	1.5	1.4	0.9	1.3	1.8
	Spring	0.7	0.8	0.8	0.8	0.5	0.5	0.8
1	Annual	0.9	1.0	1.0	1.1	0.6	0.7	1.2
	Summer	0.7	0.7	0.8	1.0	0.5	0.5	0.5
	Fall	1.2	1.3	1.4	1.5	0.8	0.9	1.7
	Winter	1.2	1.4	1.3	1.2	0.6	0.8	2.1
	Spring	0.5	0.7	0.5	0.6	0.4	0.5	0.5
2	Annual	1.3	1.3	1.2	1.6	1.1	1.1	1.2
	Summer	1.0	0.8	0.7	1.6	1.0	0.9	0.7
	Fall	1.2	1.1	1.2	1.6	1.1	1.0	1.2
	Winter	2.0	2.0	2.0	2.1	1.7	2.1	2.2
	Spring	0.9	1.2	1.0	1.1	0.7	0.5	0.8
3	Annual	0.8	0.8	0.9	0.7	0.5	0.9	1.1
	Summer	0.4	0.6	0.4	0.8	0.6	0.3	0.4
	Fall	1.0	1.0	1.2	0.7	0.5	1.0	1.4
	Winter	0.9	0.8	1.0	0.6	0.4	1.3	1.3
	Spring	0.8	0.7	0.8	0.5	0.5	0.7	1.2
7	Annual	1.0	1.0	1.2	1.3	0.6	0.7	1.1
	Summer	0.6	0.5	0.7	1.0	0.5	0.4	0.4
	Fall	1.2	1.3	1.7	1.5	0.5	0.9	1.7
	Winter	1.4	1.6	1.7	1.7	0.7	1.0	1.7
	Spring	0.7	0.8	1.0	0.9	0.4	0.4	0.7

TABLE 15
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN
PHILADELPHIA EXPRESSED AS THE RATIO OF DIURNAL
VALUES TO THE YEARLY MEAN SAMPLING INTERVAL

Site	Season	Mean	23:00	03:00	07:00	11:00	15:00	19:00
			to 03:00	to 07:00	to 11:00	to 15:00	to 19:00	to 23:00
All	Annual	1.0	0.9	0.8	1.4	0.8	1.1	1.1
	Summer	0.9	0.8	0.9	1.2	0.8	0.7	0.9
	Fall	1.2	1.1	0.9	1.7	0.9	1.2	1.3
	Winter	1.2	0.9	0.8	1.4	1.0	1.5	1.3
	Spring	0.8	0.9	0.7	1.3	0.5	0.9	0.9
10	Annual	0.7	0.8	0.6	0.8	0.5	0.6	0.8
	Summer	0.8	0.8	0.8	0.9	0.6	0.7	0.9
	Fall	0.7	0.8	0.6	0.8	0.5	0.6	0.8
	Winter	0.5	0.5	0.4	0.6	0.4	0.6	0.8
	Spring	0.7	1.1	0.7	0.9	0.3	0.5	0.7
11	Annual	0.7	0.6	0.5	1.2	0.6	0.6	0.7
	Summer	0.7	0.7	0.5	1.2	0.6	0.6	0.8
	Fall	0.8	0.8	0.7	1.2	0.7	0.7	0.8
	Winter	0.8	0.6	0.6	1.1	0.9	0.8	0.6
	Spring	0.5	0.4	0.3	1.4	0.4	0.5	0.5
12	Annual	1.1	0.8	1.0	1.5	0.9	1.2	1.2
	Summer	0.7	0.6	0.9	1.1	0.6	0.5	0.7
	Fall	1.4	0.9	1.0	1.9	1.0	1.5	1.6
	Winter	1.3	0.8	1.2	1.7	1.1	1.6	1.2
	Spring	0.9	0.8	0.7	1.2	0.7	0.8	1.0
13	Annual	2.0	1.4	1.3	2.6	2.2	2.4	2.1
	Summer	1.7	1.2	1.1	2.4	2.1	2.0	1.7
	Fall	2.5	1.5	1.5	3.5	2.7	3.0	2.6
	Winter	2.2	1.5	1.5	2.7	2.4	2.8	2.2
	Spring	1.4	1.0	0.8	1.8	1.5	1.5	1.6
14	Annual	1.4	1.1	1.4	2.1	1.0	1.2	1.4
	Summer	1.2	0.9	1.7	1.5	1.2	0.9	1.0
	Fall	1.5	1.5	1.4	2.5	0.9	1.2	1.5
	Winter	1.4	1.0	1.0	2.0	0.9	1.6	1.5
	Spring	1.3	1.1	1.2	2.4	0.9	1.0	1.4
15	Annual	0.7	1.0	0.7	0.8	0.5	0.5	0.9
	Summer	0.6	1.0	0.6	0.8	0.4	0.3	0.9
	Fall	0.9	1.2	1.0	1.1	0.5	0.5	0.8
	Winter	0.7	0.8	0.6	0.7	0.5	0.7	1.1
	Spring	0.5	1.1	0.5	0.5	0.3	0.3	0.7
16	Annual	0.5	0.6	0.5	0.6	0.5	0.5	0.6
	Summer	0.5	0.6	0.4	0.5	0.3	0.3	0.5
	Fall	0.5	0.5	0.4	0.8	0.5	0.4	0.6
	Winter	0.6	0.5	0.5	0.5	0.5	0.8	0.8
	Spring	0.5	0.6	0.5	0.5	0.4	0.4	0.5

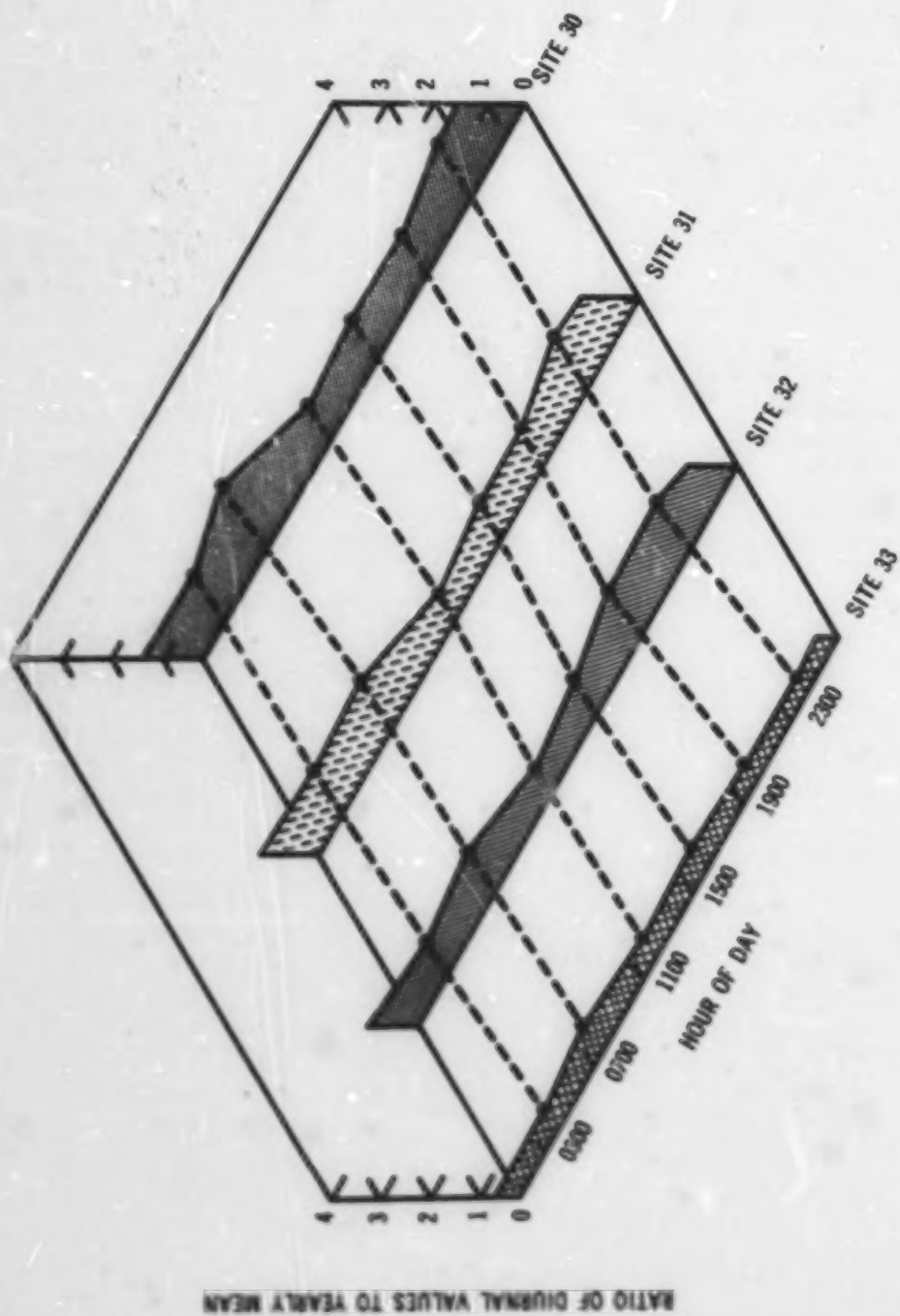


FIGURE 12
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN CINCINNATI

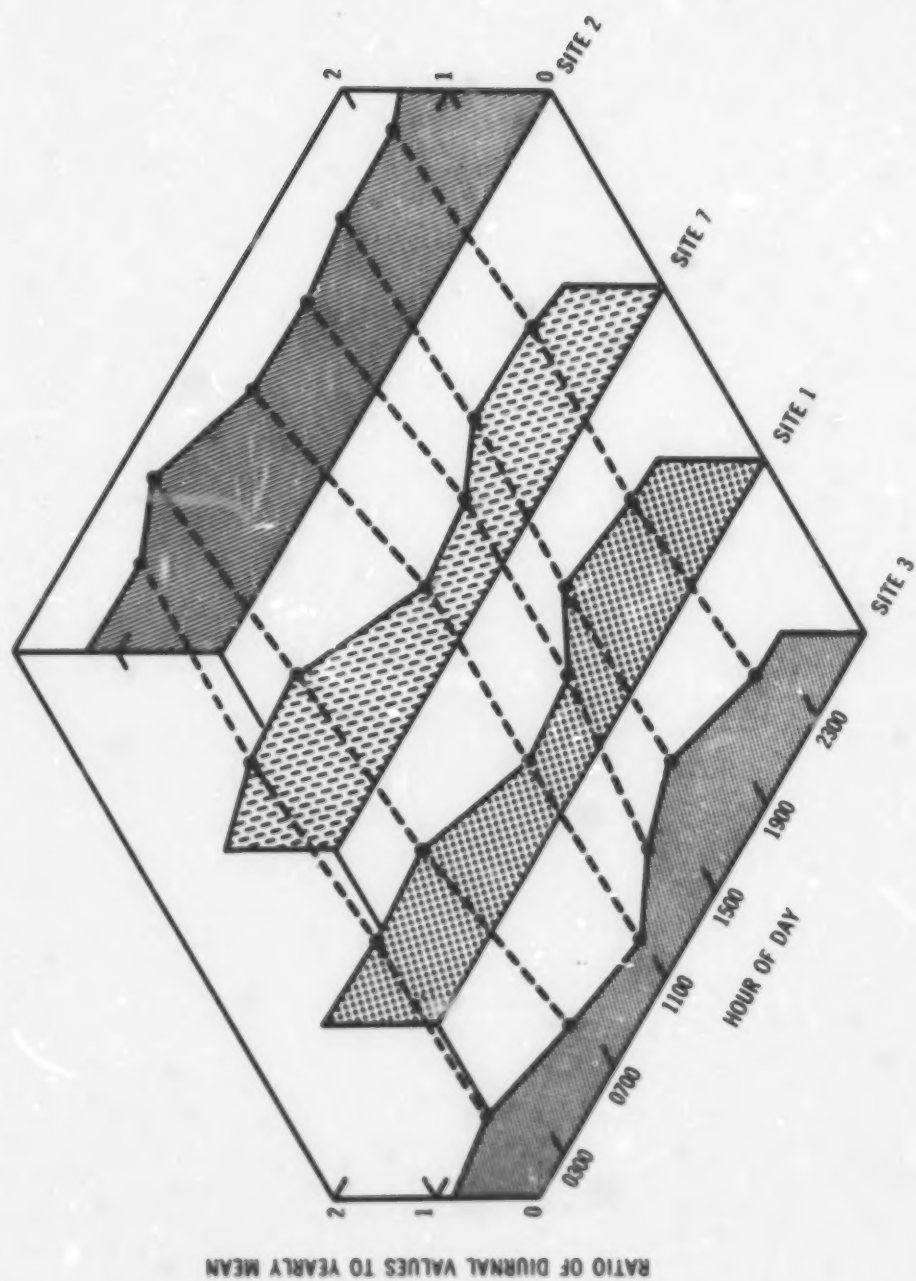


FIGURE 13
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN LOS ANGELES

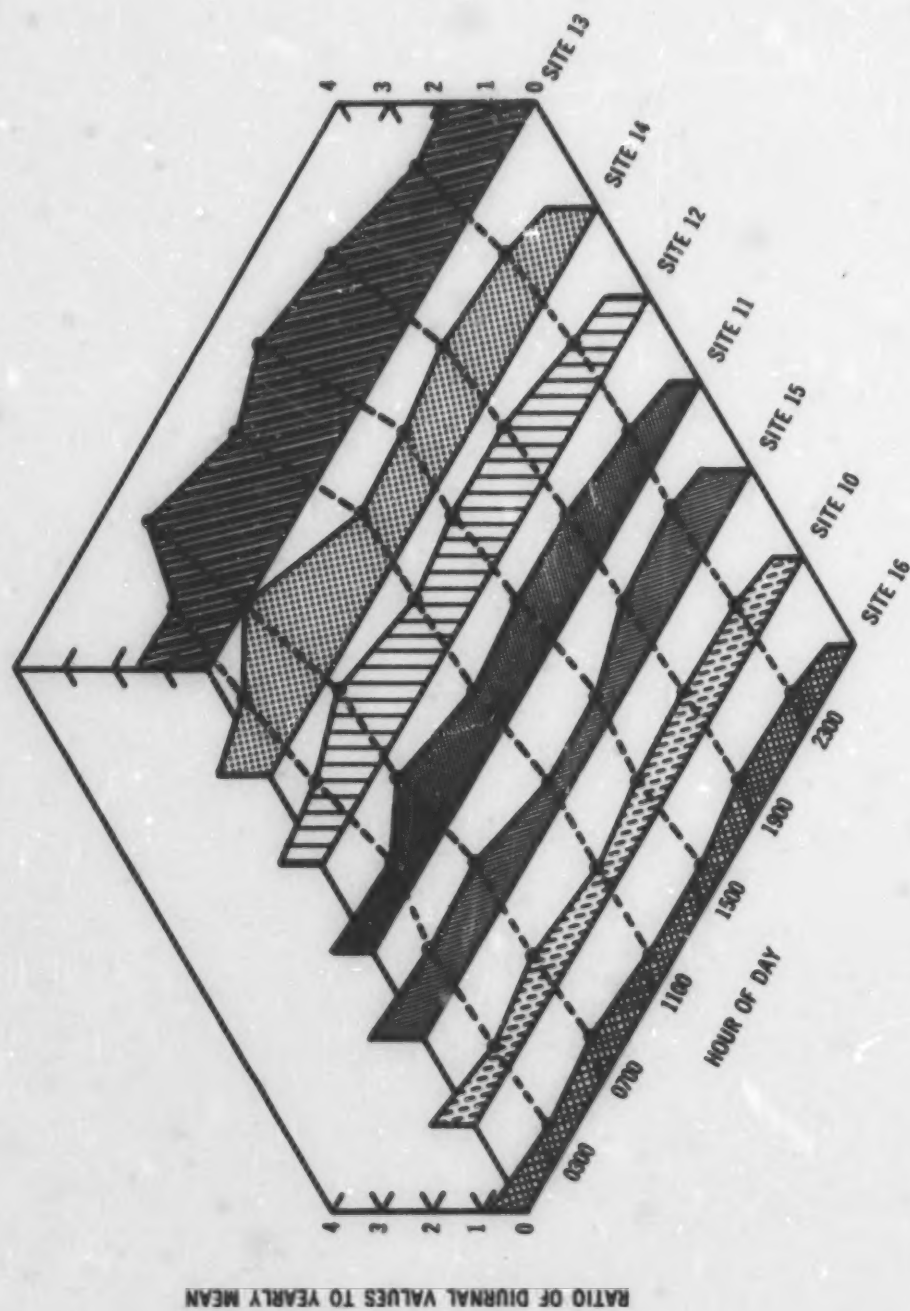


FIGURE 14
DIURNAL VARIATIONS OF ATMOSPHERIC LEAD IN PHILADELPHIA

Relation between Lead and Carbon Monoxide:

The California Department of Public Health and the Los Angeles County Air Pollution Control District have estimated that motor vehicles are the source of over 90 percent of the carbon monoxide in Los Angeles County. At three of the sampling sites in Los Angeles carbon monoxide was measured as part of the Air Pollution Control District's air monitoring program. Because motor vehicles are also a source of lead, it was decided to correlate lead concentrations against carbon monoxide concentrations at the three sites during months when highest levels of these pollutants were found. The correlation coefficients between these measures were high and approximately the same at all three locations (Table 16). Data on carbon monoxide were not available for any of the lead-sampling sites in Cincinnati and Philadelphia.

TABLE 16
CORRELATIONS BETWEEN LEAD CONCENTRATIONS
AND CARBON MONOXIDE CONCENTRATIONS AT
THREE LOS ANGELES STATIONS^a

Sampling site	Correlation coefficient	Significant at 1% level	Percent variance explained	Regression line	
				Intercept, $\mu\text{g Pb/m}^3$	Slope $\mu\text{g Pb/m}^3$ vs. ppm CO
Downtown Los Angeles	0.79	Yes	62	-9.84	1.12
West Los Angeles	0.81	Yes	66	-5.97	0.82
Pasadena	0.81	Yes	66	-6.99	0.82

^aCorrelations are between individual lead samples and average carbon monoxide concentrations for the corresponding time periods, for the months of November, December and January, 1961-1962.

Relationship of National Air Sampling Network data to three-city study data: One of the sites in each of the cities in the three-city study was selected to correspond to the National Air Sampling Network (NASN) station of the Public Health Service. Approximately 25 NASN samples were taken at each of these sites during the present study. These samples were analyzed for lead by both emission spectrometry, the usual NASN method, and the dithizone method used for the present investigations. Appropriate Millipore samples of 2- and 3-day duration were matched with the 25 NASN samples collected at each site at the same time.

Mean lead concentrations determined by NASN methods (emission spectrometry) are about the same as those determined by lead-study

methods (dithizone analysis). In Cincinnati and Philadelphia, the mean concentrations measured by NASN methods were about 10 percent higher than those measured by lead-study methods at the same location; in Los Angeles they were about 10 percent lower (Table 17).

Atmospheric lead trends: NASN stations have been in operation at one of the lead study sites in Philadelphia since 1957 and in Cincinnati and Los Angeles since 1959. Unanalyzed portions of filters used in regularly scheduled sampling have been retained by the NASN. Composites of these unused portions at each of these three sites were prepared and analyzed by the dithizone method. This method was selected because of its specificity for lead in contrast to the spectrographic method, which involves the determination of a number of metals and utilizes a single photographic plate at some sacrifice of accuracy in the determination of any one metal.

TABLE 17
COMPARISON OF ATMOSPHERIC LEAD CONCENTRATIONS
IN NATIONAL AIR SAMPLING NETWORK (NASN) AND
LEAD STUDY SAMPLES AT SAME SITES

CITY	Site number	Mean concentrations, $\mu\text{g}/\text{m}^3$			Correlation	
		Lead study	NASN	NASN Lead study	Coefficient	Percent variance
Cincinnati	30	1.5	1.7	1.13	0.82	67
Los Angeles	1	2.7	2.5	0.93	0.66	44
Philadelphia	14	1.8	2.0	1.11	0.60	36

The results of these analyses indicate that the annual average lead concentration at the Philadelphia site decreased from 2.3 micrograms per cubic meter to 1.3 during the period 1957-62 (Table 18 and Figure 15). Concentrations at Cincinnati decreased from 1.9 micrograms per cubic meter in 1959 to 0.8 in 1961, but increased to 2.1 in 1962. The reason for these fluctuations is not apparent. Lead concentrations at Los Angeles increased from 3.6 micrograms per cubic meter to 4.4 over the period 1959-62. Since air pollutant concentrations may vary significantly from year to year because of meteorological and source factors, it is not possible to establish trends on the basis of the limited period for which data are available. The data for the cities as a whole suggest that there has been little change in atmospheric lead concentrations over the past 3 years.

Kettering Laboratory has been measuring concentrations of lead in the atmosphere in Cincinnati since 1946. Data for areas corresponding

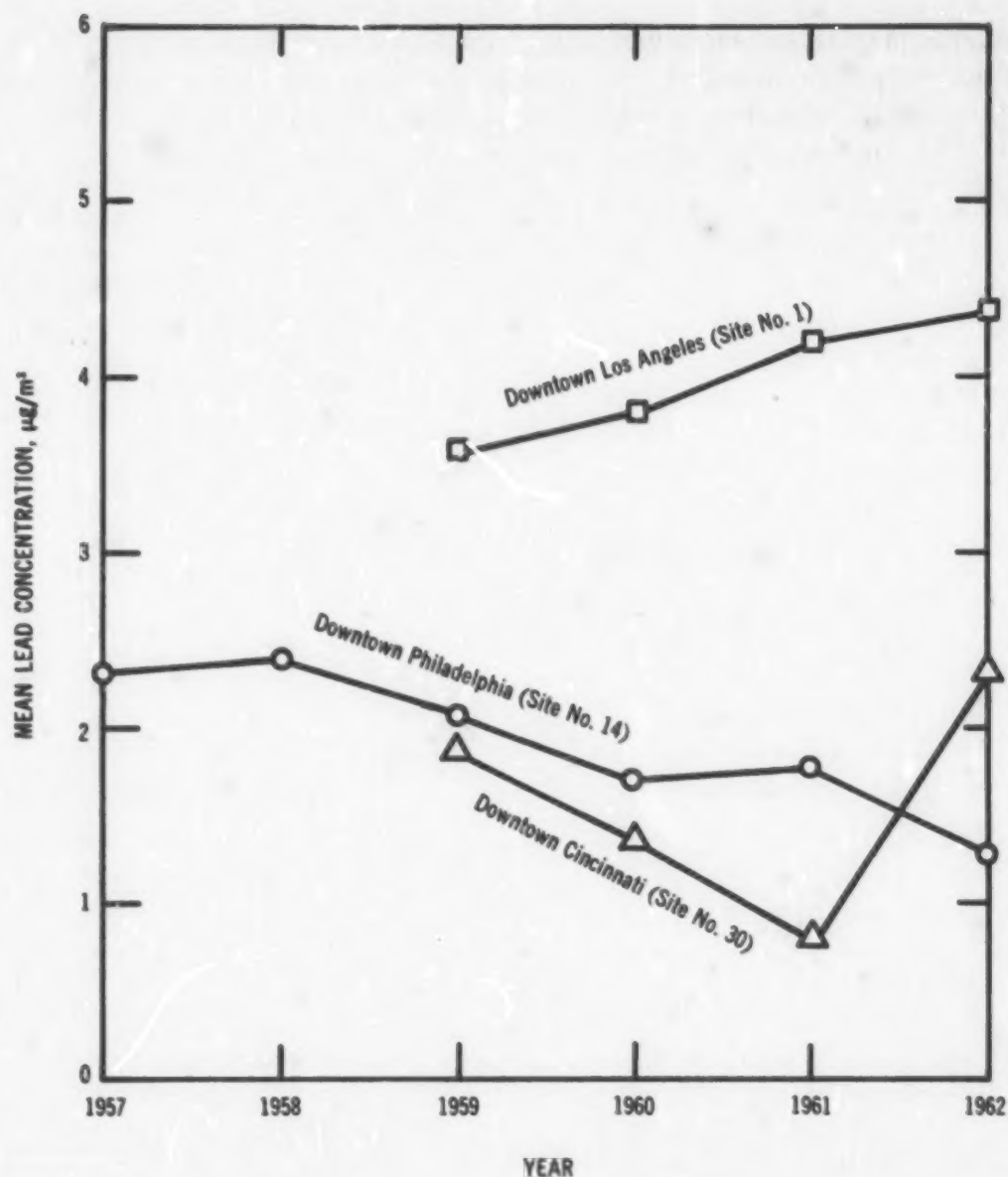


FIGURE 15

TRENDS IN THE CONCENTRATION OF ATMOSPHERIC LEAD IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA (NASN DATA)

to those included in the lead study are shown in Figure 16. The figure shows a downward trend in the central residential and basin areas from 1946 to 1954, and in the commercial areas from 1955 to 1961. No trend is apparent for the peripheral residential area. Data reported for the commercial area in Figure 16 differ from the NASN data for site No. 30 (commercial) shown in Figure 15.

The reasons for the general decline in Cincinnati since 1946 include the diminishing use of solid fuels, better collection and removal of

particulates from industrial operations, an increasingly effective enforcement of the ordinance relating to abatement of smoke, and changes in traffic flow and land use in the metropolitan area.⁷

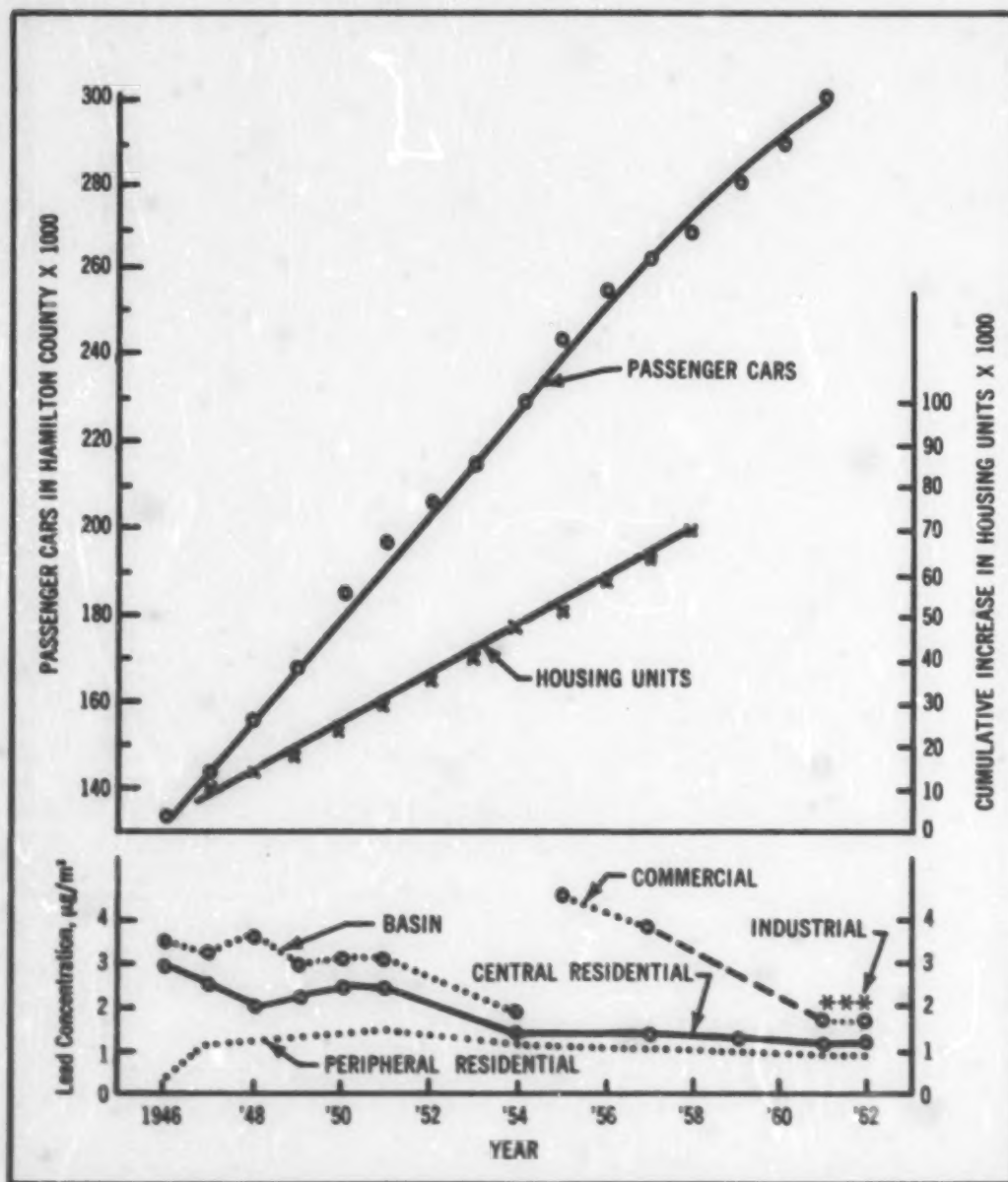


FIGURE 16
TRENDS IN THE CONCENTRATION OF ATMOSPHERIC
LEAD COMPARED WITH NUMBERS OF PASSENGER CARS
AND NEW HOUSING UNITS IN CINCINNATI

TABLE 18
ANNUAL MEAN CONCENTRATIONS OF ATMOSPHERIC
LEAD IN CINCINNATI, LOS ANGELES, AND PHILADELPHIA,
1957 through 1962 (NASN Data)

CITY	Site No.	Concentration, $\mu\text{g}/\text{m}^3$						
		1957	1958	1959	1960	1961	1962	Mean
Cincinnati	30			1.9	1.4	0.8	2.1	1.6
Los Angeles	1			3.6	3.8	4.2	4.4	4.0
Philadelphia	14	2.3	2.4	2.1	1.7	1.8	1.3	1.9

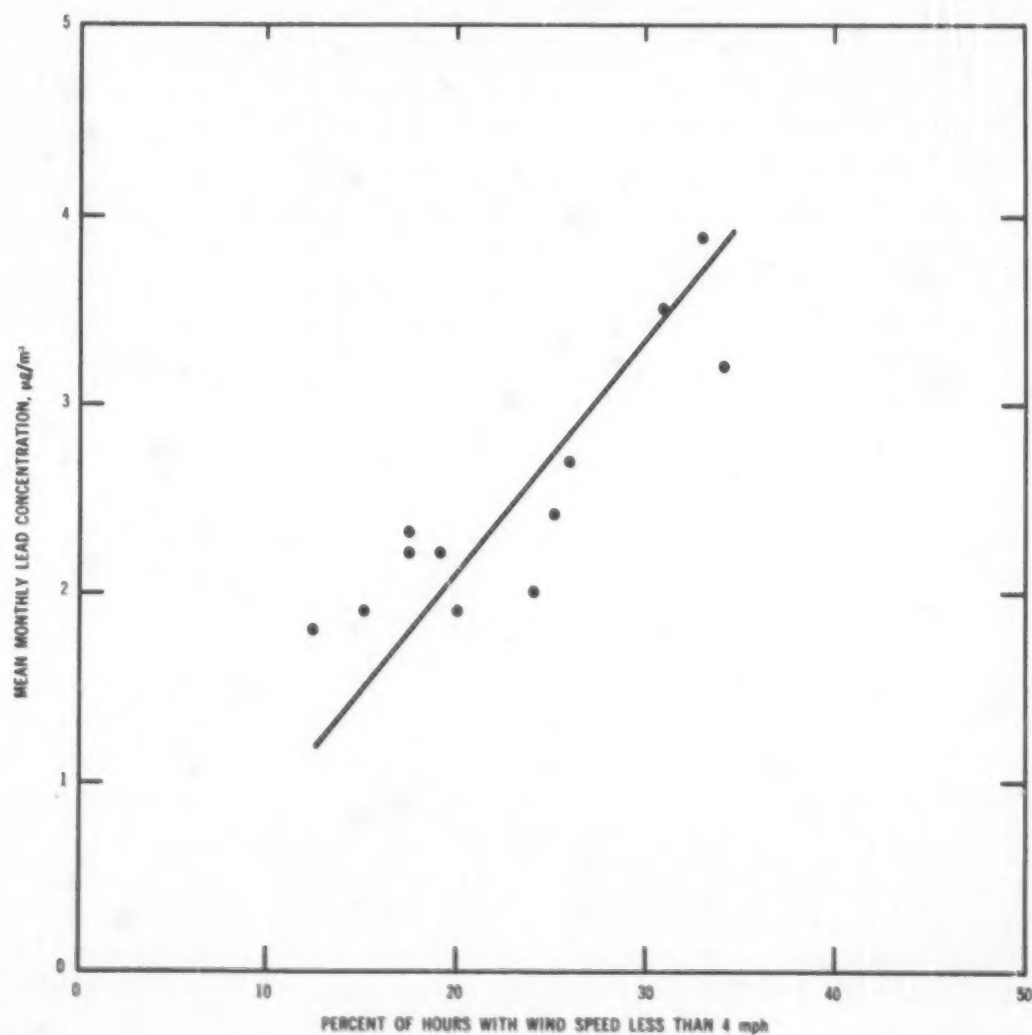


FIGURE 17
RELATIONSHIP BETWEEN ATMOSPHERIC LEAD AND
WIND SPEED IN LOS ANGELES

Meteorology

The meteorological conditions that prevailed during this investigation were examined to determine possible effects of meteorology on the atmospheric concentrations of lead and to determine the representativeness of the survey year.

Meteorological effects: Storm situations with strong winds were associated with low concentrations of lead; precipitation alone produced no significant effect, nor did flooding or snow cover. Also, increased space heating on days with record low temperatures produced no apparent effect.

High concentrations of airborne lead were associated with very low wind speeds in Los Angeles as shown by Figure 17. A similar relationship was also shown for Philadelphia and Cincinnati. Highest lead concentrations would be expected when low wind speeds are combined with a temperature inversion based at or near the surface. Inversion data for Cincinnati and Philadelphia were too meager to permit generalization. In Los Angeles, however, the period of high lead concentration did not coincide with the photochemical smog season from June to November, but occurred in December during periods of surface inversions associated with low temperatures. This is also shown by the peaking of carbon monoxide concentrations during the same period. This indicates that different meteorological factors predominate in determining lead concentrations and photochemical smog.

Representativeness of sample year: Meteorological data obtained at the Greater Cincinnati Airport are summarized in Figure 18. Precipitation during the sample year was somewhat above normal. Twice the normal amount was recorded in February; April was extremely dry. The percentage of possible sunshine was below normal much of the year. Heating requirements were slightly above normal. January was much colder than normal. Average wind speeds were near normal and were relatively constant during the sampling year. One advisory of high air pollution potential including the Cincinnati area was in effect from 3:00 p.m. August 30 to 10:00 a.m. September 1. No increase in atmospheric lead concentrations was observed, however.

Meteorological data obtained at the Los Angeles International Airport are summarized in Figure 19. Precipitation amounts were significantly large only during February, when 11 inches of rain fell. No measurable precipitation occurred in June, July, and October 1961 or in April and June 1962. Sunshine for the year was near normal except during February. Heating requirements have less meaning for the Los Angeles area than for the Philadelphia and Cincinnati areas, where the burning of coal might add lead to the atmosphere. A record high temperature of 106° occurred in Los Angeles in mid-October.

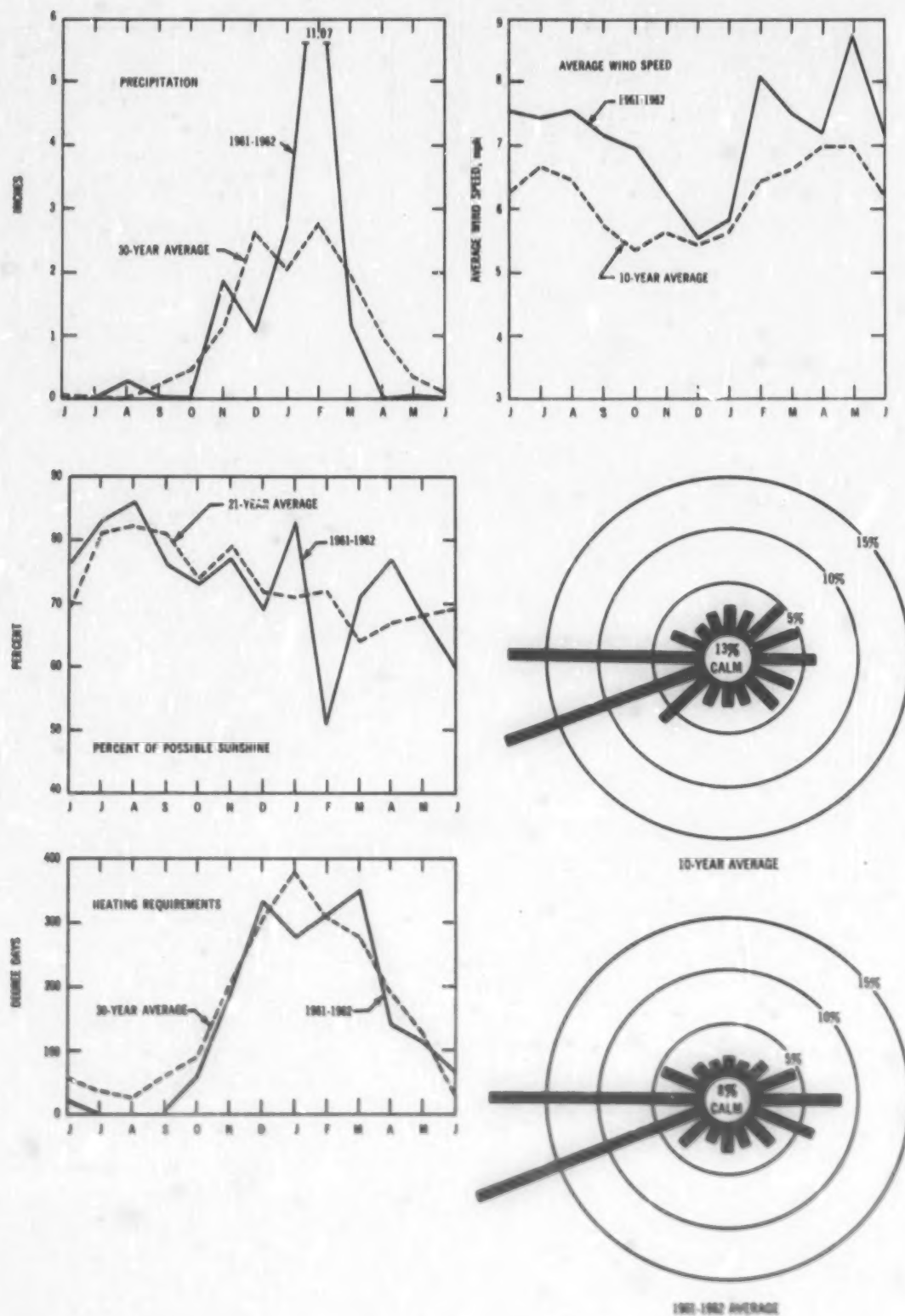


FIGURE 19
METEOROLOGICAL DATA OBTAINED AT
LOS ANGELES INTERNATIONAL AIRPORT

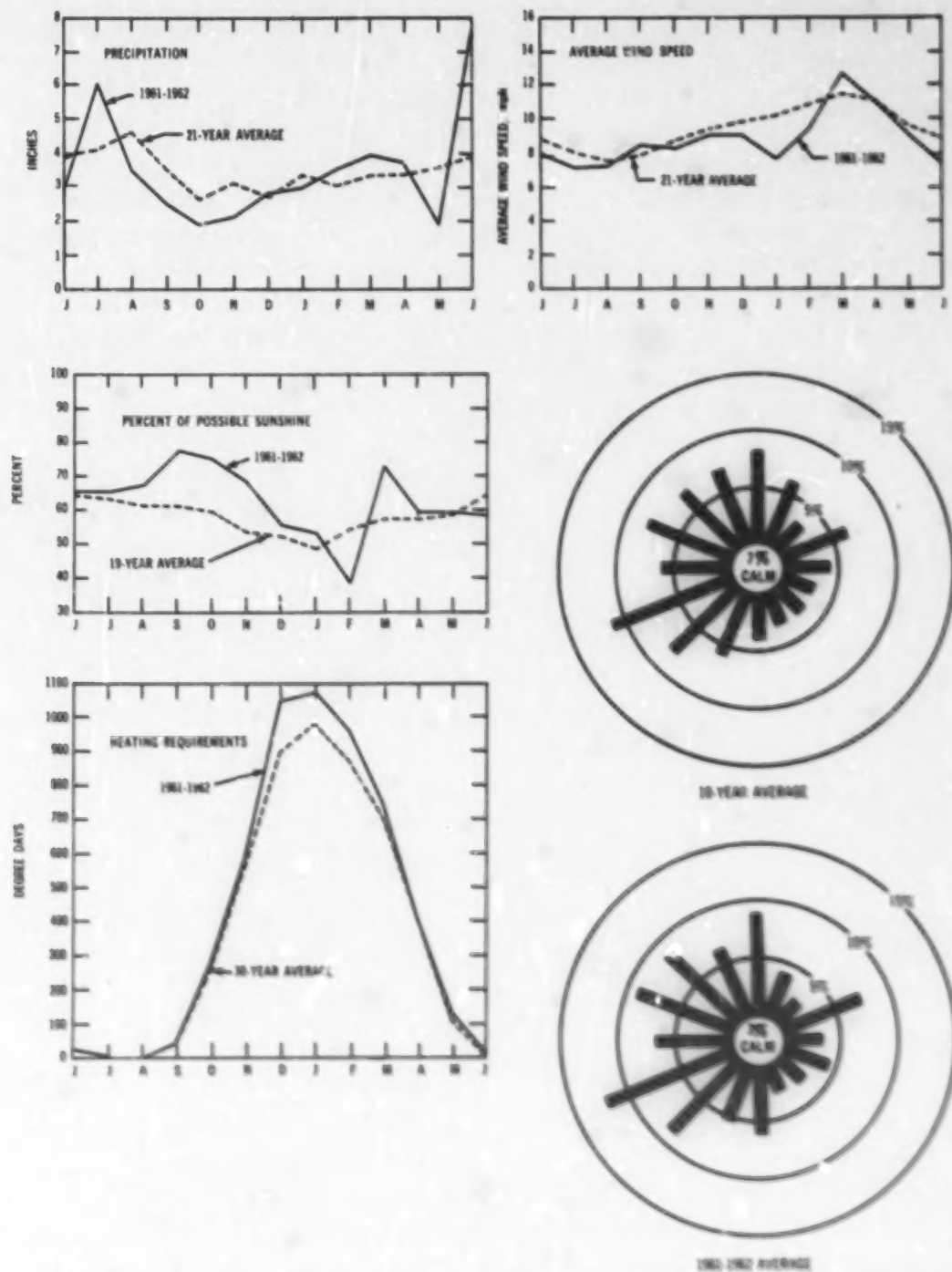


FIGURE 20
METEOROLOGICAL DATA OBTAINED AT
PHILADELPHIA INTERNATIONAL AIRPORT

Wind speeds were higher than normal at the Los Angeles International Airport during all months except December and January; in downtown Los Angeles, however, they were near normal for all months. Monthly wind directions during the study did not differ significantly from the long-term directions. In contrast to Philadelphia and Cincinnati, winds in Los Angeles were lower in December and January than during the remainder of the year. These low wind speeds probably were important factors in the relatively high concentrations of lead in the fall and winter in Los Angeles as compared to summer and spring.

Meteorological data obtained at the Philadelphia International Airport are summarized in Figure 20. Precipitation was relatively high in July 1961 and in June 1962. The percent of possible sunshine was greater than normal in all months except February. Heating requirements were above normal throughout the winter. Average monthly wind speeds were about normal throughout the year, but in March were somewhat higher. Wind direction frequencies were near normal for the period as a whole.

An advisory of high air pollution potential including the Philadelphia area began at 2:00 p.m., October 10, and ended at 3:00 p.m., October 13, 1961. During the alert, 24-hour average wind speeds measured at the Philadelphia International Airport were 4.5 mph on the 10th; 4.6 mph on the 11th; 6.3 mph on the 12th; and 7.1 mph on the 13th; the mean monthly speed is 8.9 mph. From the 11th through the 13th, surface visibility was restricted by smoke and haze to less than 7 miles. The particulate sample taken during this period at the Philadelphia NASN station was the second highest loading of the year. The highest lead concentrations for the month occurred during this period and were 1.5 to 2.0 times the monthly mean at each site.

SPECIAL STUDIES

Lead Concentrations in Heavy Traffic

Samples were obtained in Cincinnati and Los Angeles by means of mobile samplers to determine atmospheric levels of lead in or near heavy traffic streams. The samples were collected during the morning and afternoon traffic rush and during midday on representative traffic arteries. In addition, samples were taken while the test vehicles were parked at the curb at various downtown locations.

Two station wagons were used for this work; Kettering Laboratory operated the one in Cincinnati, and the Public Health Service operated the one in Los Angeles. Both were equipped with gasoline-powered generators, pumps, and air filters. Samples were taken from the left and right rear windows and from positions within the station wagon near the driver's head. Similar values were obtained for all of these

positions. Samples were collected with the same equipment and analyzed in the same manner as were those collected at the fixed stations.

In the Cincinnati area, 140 samples were taken; in Los Angeles, 191. Results are summarized in Tables 19 and 20.

In Los Angeles traffic, atmospheric lead levels were about 25 micrograms per cubic meter, whereas in Cincinnati the values were about 14. Successively lower values were found at greater distances from the traffic; e.g., values obtained at curbside along a busy residential street in Cincinnati with 503 cars per hour averaged 4.6, and those on a country road averaged about 3.

Other studies have illustrated the variability of lead concentrations and their relationship to automobile sources."

TABLE 19
ATMOSPHERIC CONCENTRATIONS OF LEAD IN TRAFFIC
CINCINNATI AREA
(IN MICROGRAMS PER CUBIC METER)

Description of Route	No. of Samples	Mean	Range
I Mobile sampling in traffic			
7 Commuter Routes, Morning Rush	20	14.2	7.2-19.5
7 Commuter Routes, Afternoon Rush	8	15.2	9.3-21.1
7 Commuter Routes, Midday	8	9.1	7.0-12.3
Streets Loaded Heavily, 2150 Cars/Hr.	35	14.3	9.0-26.7
Downtown during Afternoon Rush	3	11.5	8.6-15.8
II Fixed Position Sampling			
Parked at Curb, Downtown, Christmas Rush	4	21.4	17.7-24.4
Parked at Curb, 2150 Cars/Hr.	12	7.6	3 -15
Parked at Curb, 820 Cars/Hr.	13	4.8	1 -11
Parked at Curb, 500 Cars/Hr.	15	4.6	1 - 9
Parked at Curb, 220 Cars/Hr.	5	1.9	1 - 3
III Mobile Sampling—Rural			
Cruise at 30-40 Mph.	13	3.1	0.6- 6.6
Stop and Go behind Another Car	4	4.3	1.7- 6.5
TOTAL	140		

TABLE 20
ATMOSPHERIC CONCENTRATIONS OF LEAD IN TRAFFIC—LOS ANGELES AREA
(IN MICROGRAMS PER CUBIC METER)

Route	Sampling Time	Day of Week	Description	Mean	Range	No. of Samples
Parked Along Freeway ^a	0600-0900	Weekdays	Morning Rush	38.0	26.9-54.3	7
Parked Along Freeway	0900-1600	Weekdays	Midday	24.1	16.6-31.1	7
Parked Along Freeway	1600-1800	Weekdays	Afternoon Rush	18.4	8.7-25.4	7
Parked Along Freeway	—	Saturday	—	19.9	17.7-22.2	4
Freeway Traffic	0600-0900	Weekdays	Morning Rush	29.3	10.9-41.3	35
Freeway Traffic	0900-1600	Weekdays	Midday	21.5	4.5-39.2	39
Freeway Traffic	1600-1800	Weekdays	Afternoon Rush	22.2	10.5-43.1	34
Freeway Traffic	—	Saturday	—	25.3	10.0-71.3	32
Los Angeles Downtown Traffic	0600-0900	Weekdays	Morning Rush	23.6	19.1-29.9	6
Los Angeles Downtown Traffic	0900-1600	Weekdays	Midday	10.5	8.4-12.2	4
Los Angeles Downtown Traffic	1600-1800	Weekdays	Afternoon Rush	15.3	12.4-18.6	4
Los Angeles Downtown Traffic	—	Saturday	—	9.4	8.6-10.3	4
Pasadena Downtown Traffic	0600-0900	Weekdays	Morning Rush	—	—	—
Pasadena Downtown Traffic	0900-1600	Weekdays	Midday	11.9	8.6-14.6	6
Pasadena Downtown Traffic	1600-1800	Weekdays	Afternoon Rush	—	—	—
Pasadena Downtown Traffic	—	Saturday	—	12.4	12.3-12.4	2
			TOTAL			191

^aParked on shoulders of major freeway in downtown Los Angeles.

Sumner Tunnel Study

The atmosphere in Boston's Sumner Tunnel was studied in July and September 1961. The 35,000 vehicles per day that traversed the then two-way tunnel produced an average carbon monoxide concentration of 70 parts per million in the tunnel. Inlet air contained an average of 1.1 micrograms of lead per cubic meter, and outlet air contained 44.5. Similar increases were noted for other pollutants measured.²⁹

In Miranda's study of the lead concentrations in the blood of 47 of these tunnel employees, the overall mean concentration was 0.03 milligram per 100 grams of blood. He also observed that concentrations of lead in the blood of long-term employees who smoked were higher than those of all other employees combined.³⁰

Alkyl Lead Concentrations

The values of lead reported for the three-city study are for the inorganic lead content of the atmosphere. Although this form of lead predominates in the atmosphere, some alkyl lead in the form of vapor is present. The primary source of this alkyl lead is the alkyl lead vapors associated with unburned gasoline, as discussed earlier. Small quantities of these alkyl lead compounds escape to the atmosphere from several points on a motor vehicle. In addition, these compounds are introduced into the atmosphere whenever leaded gasoline is spilled or evaporated.

Because alkyl lead vapors are present in very small concentrations, large samples of air must be collected for their measurement. Three sampling systems were tried: (1) A total volume of 0.23 cubic meter of air was first passed through a membrane filter to remove particulate lead and then drawn through a scrubber containing 1 gram of crystalline iodine. (2) A total volume of 1.2 cubic meters of air was first passed through a membrane filter and then drawn through two scrubbers, in series, containing 1 N solution of iodine. (3) A total volume of 2 cubic meters of air was first passed through a membrane filter and then drawn through a scrubber containing 20 grams of crystalline iodine. In each sampling system, the membrane filter and the contents of the scrubber system were analyzed separately.

Alkyl lead samples were collected in heavy traffic in the Cincinnati area by use of the mobile sampler. Data are summarized in Table 21. Results were inconsistent in that alkyl lead concentrations varied inversely with the volume of air sampled. This indicates that the sampling and analytical procedures are not adequate to quantitate the low concentrations of alkyl lead compounds that may be present in the atmosphere. Similar inconsistent results were obtained for sampling in heavy traffic in the Los Angeles area. Evaluation of the levels of these compounds in the atmosphere requires the development of improved sampling and analytical procedures. Although it is not possible to assign any degree of reliability to the values shown in Table 21, the

TABLE 21
CONCENTRATIONS OF ALKYL LEAD VAPORS
IN THE ATMOSPHERE IN HEAVY TRAFFIC
IN THE CINCINNATI AREA

Sampling procedure	Air sampled, m ³	No. of Samples	Concentration of lead, $\mu\text{g}/\text{m}^3$			
			Alkyl lead		Inorganic	
			Mean	Range	Mean	Range
Iodine crystal (1 g)	0.23	8	2.1	0.9-3.5	16.0	8.4-28
Iodine solution	1.2	15	1.1	0.4-2.4	11.1	2.5-19.5
Iodine crystal (20 g)	2.1	3	0.2	0.1-0.2	15.5	1.3-23.5

results do indicate that at most the alkyl lead concentrations did not reach 10 percent of the inorganic lead values, and probably were considerably less.

BIOLOGICAL STUDIES

In conjunction with the atmospheric studies, investigations were conducted to determine the lead content of the blood and urine of selected population groups in the three cities. In general, the subjects were selected on the following bases:

1. Most of the individuals had no known industrial exposure to lead. A few groups were selected who had some opportunity for occupational exposure.
2. The range of ages was as wide as possible.
3. Within specific groups, an equal number of males and females was selected wherever possible.
4. All subjects lived in the survey areas for at least 5 years.

The general procedure employed in Philadelphia and Los Angeles was to draw from each subject one sample of blood of from 10 to 20 milliliters through a lead-free stainless-steel needle into a lead-free Vacutainer. A single specimen of urine was taken from each male subject at the time the blood sample was drawn. After digestion of the blood and urine samples, a dithizone analysis similar to that previously described was performed to determine the total lead content.²⁷ The procedure in Cincinnati differed somewhat in that duplicate samples of blood were obtained for analysis by spectrography in addition to analysis by the dithizone method. A social and medical history, including smoking habits, was obtained from each individual.

Because there were some differences in the detailed procedures of the biological phase of the program in the three cities, each study is discussed individually.

Cincinnati

Populations Studied: In Cincinnati, the procedures for investigating biological effects of general environmental exposure to lead differed somewhat from those employed in Philadelphia or Los Angeles. Many persons in Cincinnati had been investigated in this manner previously, most recently in the winter of 1955-56. In that survey of approximately 500 persons, feces as well as blood and urine had been sampled and subjected to analysis for lead. Very little more was learned concerning the contribution made by atmospheric contamination to the absorption and excretion of lead than had been learned in previous investigations of this type. It was hoped, therefore, that in the three-city survey, by judicious selection of groups of persons in the population, it might be possible to determine the relative importance of the atmospheric source.

For these and other reasons, subjects were sought who had experienced more than the usual opportunities for respiratory exposure to the principal sources of lead in the atmosphere of Cincinnati. The most promising groups were those who spent most of their working hours regularly in the streets and on the sidewalks of the city close to its motor traffic. In this category are city police (traffic officers in particular); postal employees, especially letter carriers on foot and in motor cars; city firemen; and certain peripatetic, technical employees of the City Health Department (housing inspectors and air pollution inspectors). Professional drivers of motor vehicles, such as taxicab and delivery truck drivers, were regarded as desirable subjects, but were not readily available. Only 14 taxicab drivers were examined; results of these analyses are given in this report but are not considered representative of this occupational group because of the small sample size.

To encompass other segments of the Cincinnati population, results of observations made in the winter of 1955-56 on 478 persons in Cincinnati and vicinity are recorded. The analytical data were obtained by the same methods of analysis and are comparable in every respect to those obtained in this survey. Not only is this additional number of persons important, but their locations and types of employment in relation to combustion products of automotive engines broaden the scope of the investigation significantly.

Results: The principal analytical data of the two surveys have been assembled in Tables 22 and 23, according to the frequencies of occurrence of various ranges of the concentration of lead in the blood and urine.

Table 22 gives the blood analyses. The outstanding example, on the high side, is garage mechanics. A small group of men employed in

TABLE 22
DISTRIBUTION OF PERSONS IN VARIOUS OCCUPATIONAL GROUPS ACCORDING TO
CONCENTRATIONS OF LEAD IN BLOOD—CINCINNATI

Lead in blood, mg/100g	Service station attendants		Refinery handlers of gasoline		Parking attendants		Garage Mechanics		Drivers of cars		Police		Firemen		Post-Office Emp.		City Health Dept. Emp.	
	1956	1956	1956	1956	1956	1956	1956	1956	1956	1963	Traffic officers 1956	All police ^a 1963	1963	1963	1963	1963	1963	1963
0-0.009																		
0.010-0.019	1	2							1		3	12	18	22	10			
0.020-0.029	42	30	1			8		17	4	7	23	78	123	90	24			
0.030-0.039	71	46	26			43		19	9	9	9	27	44	24	2			
0.040-0.049	14	8	20			72		9		1	4	5	6	2				
0.050-0.059	2					25								1				
0.060-0.069			1			4				1	1	1		1				
Totals	130	86	48			152		45	14	17	40	123	191	140	36			
Mean	0.028	0.027	0.034			0.038		0.033	0.031	0.031	0.030	0.025	0.025	0.023	0.021			
Std. Dev.	0.007	0.006	0.006			0.009		0.006	0.006	0.006	0.009	0.007	0.006	0.007	0.005			

^aIncludes traffic officers for 1963.

TABLE 23

DISTRIBUTION OF PERSONS IN VARIOUS OCCUPATIONAL GROUPS ACCORDING TO
CONCENTRATIONS OF LEAD IN URINE—CINCINNATI

Lead in urine, mg/l	Service station attendants		Refinery handlers of gasoline		Parking attendants		Garage Mechanics		Drivers of cars			Police		Firemen		Post-Office Emp.		City Health Dept. Emp.	
	1956	1956	1956	1956	1956	1956	1956	1956	1956	1963	1963	Traffic officers	All police ^a	1963	1963	1963	1963	1963	1963
0-0.009	1	1	1	1	1	1	4	1				2	2						
0.010-0.019		1	1	4	4	2	2	28				9	6	47	49	12			
0.020-0.029	74	49	21	21	39	39	39	11	5			5	29	71	52	18			
0.030-0.039	33	22	12	12	33	33	33	2	4			7	21	36	19	6			
0.040-0.049	13	9	7	7	30	30	30	2	4			3	8	19	9	1			
0.050-0.059	5		2	2	21	21	21		1			2	12	9	1				
0.060-0.069	3	4	1	1	16	16	16					1	7	2					
0.070-0.079					4	4	4	1				1	3	1					
0.08-0.12	1				3	3	3					3	6						
Totals	130	86	48	48	152	152	152	45	14	17	37	116	185	130	37				
Mean	0.027	0.028	0.028	0.028	0.040	0.040	0.040	0.020	0.036	0.023	0.039	0.038	0.027	0.022	0.022				
Std. Dev.	0.010	0.013	0.011	0.011	0.020	0.020	0.020	0.011	0.010	0.011	0.020	0.018	0.011	0.009	0.007				

^aIncludes traffic officers for 1963.

several parking garages and parking lots (investigated in 1955-56) is next in order on the high side, and a correspondingly small group of regular drivers of motor cars (also investigated in 1955-56) comes next and is almost paralleled by the small group of taxicab drivers included in the present survey. Next in descending order come the traffic officers, and with insignificant difference, the larger group of policemen of which they are a part. From here on down from the mid-point in the sequence of mean values come firemen, post-office personnel, and the peripatetic technical personnel of the City Health Department. Despite the small ranges of the individual findings and of the mean concentrations of lead in the blood of several groups, the differences between the groups reach statistical significance at several intervals from the lowest to the highest.

The degree of variability of the concentrations of lead in the specimens of the urine (Table 23) of nearly 1000 persons in these divergent walks of life is remarkably small, the total range extending from 0.005 to 0.12 milligram per liter. This indicates that quantities of lead absorbed by the individuals in these groups from day to day, while highly variable, are uniformly small. There are significant differences in the groups, however; the outstanding example is that of the garage mechanics. Other groups, notably the police officers as an entire group, and a fairly sizable subgroup of traffic officers, are in the relatively high zone of the total spectrum of mean values.

One may postulate under these conditions that such a variable as the atmospheric lead content, if distributed in sufficiently distinctive orders of magnitude in well-defined areas of a city, would reveal its effects in a distinctly variable manner through the responses of the residents of these areas. Accordingly, to determine the significance of one factor that might contribute to the differentiation of the exposure to airborne lead of individuals within the several groups, the subjects were classified according to four general areas in which their homes were situated: industrial, commercial, residential, or rural. The results of the examination of the analytical data arranged in this manner are shown in Tables 24 and 25. No valid or consistent relationship between these areas and the lead content of the blood and urine was established.

Another variable in the experience of the subjects—their habits of smoking—was examined in considerable detail because of its possible effect in masking or distorting the physiological response to lead in the general atmosphere. For reasons set forth earlier, it was not anticipated that this effect would be striking or even certainly discernible. The data that are available in sufficient numbers to be worthy of statistical examination are assembled in Table 26.

It is evident that the differences between smokers and nonsmokers of cigarettes in the several groups of subjects, while very small and statistically not significant, are with one exception (concentration of

TABLE 24
CONCENTRATIONS OF LEAD IN BLOOD FOR FOUR VOCATIONAL GROUPS
DISTRIBUTED ACCORDING TO HOME ADDRESSES—CINCINNATI

Vocational Group	Industrial			Commercial			Residential			Rural		
	Number	Mean, mg/100g	Std. dev.	Number	Mean, mg/100g	Std. dev.	Number	Mean, mg/100g	Std. dev.	Number	Mean, mg/100g	Std. dev.
Policemen	10	0.026	0.007	12	0.029	0.011	85	0.024	0.006	10	0.029	0.005
Firemen	5	0.026	0.004	22	0.026	0.007	148	0.025	0.006	16	0.022	0.004
Post-Office Employees	20	0.022	0.005	14	0.026	0.011	68	0.024	0.007	17	0.023	0.005
Health Department Employees	1	0.025		6	0.021	0.005	24	0.021	0.005	3	0.025	0.005
All Groups	36	0.023		54	0.025		325	0.024		46	0.023	

TABLE 25
CONCENTRATIONS OF LEAD IN URINE FOR FOUR VOCATIONAL GROUPS
DISTRIBUTED ACCORDING TO HOME ADDRESSES—CINCINNATI

Vocational Group	Industrial			Commercial			Residential			Rural		
	Number	Mean, mg/l	Std. dev.	Number	Mean, mg/l	Std. dev.	Number	Mean, mg/l	Std. dev.	Number	Mean, mg/l	Std. dev.
Policemen	9	0.048	0.019	12	0.037	0.024	80	0.037	0.017	10	0.040	0.016
Firemen	5	0.027	0.008	21	0.026	0.011	143	0.027	0.011	16	0.025	0.012
Post-Office Employees	18	0.020	0.005	14	0.020	0.010	63	0.023	0.009	15	0.020	0.006
Health Department Employees	1	0.020		6	0.020	0.004	23	0.022	0.008	3	0.030	0.009
All Groups	33	0.028		53	0.026		309	0.028		44	0.027	

TABLE 26
CONCENTRATIONS OF LEAD IN BLOOD AND URINE FOR FOUR VOCATIONAL GROUPS
DISTRIBUTED AS SMOKERS AND NONSMOKERS—CINCINNATI

Subjects	Subgroup	Lead in blood, mg/100g			Lead in urine, mg/l		
		Number	Mean	Std. dev.	Number	Mean	Std. dev.
Policemen	Smokers	107	0.025	0.007	104	0.038	0.019
	Nonsmokers	11	0.023	0.006	8	0.039	0.013
Firemen	Smokers	163	0.025	0.006	158	0.027	0.012
	Nonsmokers	27	0.024	0.006	26	0.026	0.008
Post-Office Employees	Smokers	118	0.024	0.006	109	0.023	0.009
	Nonsmokers	20	0.022	0.010	19	0.019	0.007
Health Department Employees	Smokers	30	0.022	0.005	29	0.023	0.007
	Nonsmokers	5	0.016	0.002	5	0.018	0.004
All Subjects 1963	Smokers	418	0.024	0.006	400	0.028	0.014
	Nonsmokers	63	0.022	0.007	58	0.025	0.010
All Smokers	Inhale	294	0.024	0.006	282	0.029	0.012
	Do Not Inhale	46	0.022	0.005	43	0.025	0.010
All Smokers of Cigarettes	Unfiltered	173	0.022	0.005	168	0.037	0.017
	Filtered	131	0.024	0.006	123	0.023	0.010

lead in the urine of policemen) in the same direction; i.e., they show a trend toward the occurrence of larger quantities of lead in the blood and urine of smokers than of nonsmokers. This trend, in view of its essential uniformity within the group, is sustained in the comparison of all of the smokers with all of the nonsmokers. It is important to recognize, however, that the differences between the vocational groups are influenced either slightly or not at all by the factor of smoking. Obviously, therefore, the factor that differentiates policemen from post-office employees, whatever it may be, is much more potent than the factor of smoking. The differences between smokers with respect to whether or not they inhale are favorable to the hypothesis that more lead is absorbed by those who inhale. Just what can be made, other than as the intervention of chance, of the contradictory findings yielded by the urine and blood of men who smoke unfiltered as compared to filtered cigarettes is not apparent.

Additional relationships between the levels of lead in the urine and blood of the subjects in vocational and combined groupings were investigated statistically. Included in these were such factors as the age of the subjects, the duration of their employment in their specific vocational categories, the source of their water supply, the type of heating and cooking devices in their homes or quarters, certain physical ailments (specifically, pulmonary, renal, and hepatic diseases), and the frequency and severity of effects suggestive of exposure to significant concentrations of carbon monoxide, such as headaches, dizziness, and feelings of undue tiredness, singly and in combination. No correlations between these factors and the data indicative of variable levels of absorption of lead were discovered. Tables 27 and 28, which present data with respect to the age of members of two of the groups versus the concentrations of lead in the blood and urine, illustrate the procedure as well as the lack of relationship that characterized this group of variables.

TABLE 27
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
POLICEMEN BY AGE GROUPS—CINCINNATI

Age, Years	Lead in blood, mg/100g			Lead in urine, mg/l		
	Number	Mean	Std. dev.	Number	Mean	Std. dev.
20-29	15	0.028	0.005	17	0.053	0.017
30-39	42	0.027	0.005	38	0.046	0.025
40-49	46	0.028	0.008	41	0.041	0.019
50-59	18	0.026	0.007	17	0.053	0.012

TABLE 28
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
FIREMEN BY AGE GROUPS—CINCINNATI

Age, Years	Lead in blood, mg/100g			Lead in urine, mg/l		
	Number	Mean	Std. dev.	Number	Mean	Std. dev.
20-29	25	0.026	0.008	28	0.028	0.014
30-39	108	0.027	0.005	97	0.031	0.011
40-49	35	0.028	0.005	33	0.025	0.009
50-59	25	0.026	0.006	24	0.029	0.009
60-69	3	0.030	—	3	0.035	—

Los Angeles

Populations studied: The Los Angeles study was designed to compare the levels of lead in the blood and urine of groups exposed to different degrees of air pollution during their normal daily activities. In the selection of subjects, the fact that people often work and live in widely different areas was considered, and exposure to air pollution in both places was taken into account. Another factor considered was the daily exposure during time spent commuting to and from work and the types of traffic encountered.

The choice of participants was governed by the availability of groups from which volunteers could be obtained. Interest in the project and a guarantee of cooperation were obtained from the Los Angeles Police Department, a group of municipal employees in Pasadena, and employees in an aircraft plant. Specifically, the following groups were selected for study on the basis of responses to a questionnaire.

1. Individuals who worked and lived in the coastal portion of the Los Angeles Basin in which levels of atmospheric lead were assumed to be lower than in areas farther inland (aircraft employees).
2. Individuals who worked in the coastal area and lived in one of two inland areas (aircraft employees).
3. Individuals who were exposed to heavy pollution from motor vehicle exhaust because of their occupation (policemen working in Los Angeles downtown traffic).
4. Individuals who worked and lived in an inland area (municipal employees).

For each group information was obtained on amount and type of commuting.

Involved in this program were 141 Los Angeles policemen, 291 male aircraft-plant employees, 87 female aircraft-plant employees, and 150 Pasadena municipal employees. In addition, several groups of chronically ill individuals were studied.

TABLE 29

CONCENTRATIONS OF LEAD IN BLOOD BY SEX AND BY SMOKING HABITS
PILOT STUDY—OAKLAND AND LOS ANGELES—1960
(IN MILLIGRAMS OF LEAD PER 100 GRAMS OF BLOOD)

Sample, by smoking habit	Males			Females		
	Number	Mean	Std. dev.	Number	Mean	Std. dev.
TOTAL	81	0.021	0.008	93	0.017	0.008
<u>Oakland:</u>						
Total	36	0.022	0.009	53	0.018	0.009
Non smokers	19	0.019	0.007	32	0.015	0.007
Cigarette Smokers:						
Less than 10 cigarettes/day	—	—	—	9	0.025	0.013
10 or more cigarettes/day	9	0.029	0.012	12	0.022	0.008
Other Smokers	8	0.023	0.007	—	—	—
<u>Los Angeles:</u>						
Total	45	0.020	0.008	40	0.016	0.006
Non smokers	25	0.020	0.010	20	0.016	0.006
Cigarette Smokers:						
Less than 10 cigarettes/day	3	—	—	11	0.011	0.004
10 or more cigarettes/day	16	0.020	0.006	9	0.021	0.005
Other Smokers	1	—	—	—	—	—

Pilot Studies: In the summer of 1960, a pilot study was conducted in Oakland and Los Angeles to devise techniques and to test the interview schedule for use in the larger study described in this report. The sample was drawn from persons receiving routine examinations at the Northern California Kaiser Foundation Clinic (Oakland) and the Southern California Kaiser Foundation Clinic (Los Angeles). Each volunteer was interviewed and a blood specimen was drawn. The results of this study are shown in Table 29.

Other data were collected as part of a multiphase examination of residents of Alpine County, a rural area in the Sierra Nevada. Most of these persons are of American Indian ancestry. The results are presented in Table 30.

TABLE 30
CONCENTRATIONS OF LEAD IN BLOOD OF RESIDENTS
OF A RURAL CALIFORNIA COUNTY

	Number	Mean concentration, mg/100g
Total	37	0.011
Male	16	0.012
Female	11	0.009
Sex Not Stated	10	0.013

Data Collected: In order to attribute observed differences in lead concentrations to differences in exposure to air pollution, it is necessary to control, either in selection of the sample or in analysis, the other variables that might be expected to affect the concentration of lead. Therefore, individuals participating in the study were asked questions concerning occupational and residence history, smoking, chronic conditions involving the liver, kidney, and lung, occupational illness, and time taken for commuting. The usual identifying information was asked permitting use of age and sex as variables. Basically, the analytical problem was one of comparing the mean lead values obtained in the different groups classified according to their presumptive exposure and other pertinent characteristics.

Results: Table 31 shows the distribution of lead values in blood (milligrams of lead per 100 grams of blood) by sex and employment group. Table 32 shows comparable data for lead values in urine (milligrams per liter). No urine specimens were obtained from female subjects. The differences between the means of the groups are in all cases small; the ranges are not large, and nearly all individual measurements are well below 0.05. The highest mean levels for both urine and blood

TABLE 31
DISTRIBUTION OF SUBJECTS IN VARIOUS OCCUPATIONAL
GROUPS ACCORDING TO CONCENTRATION
OF LEAD IN BLOOD—LOS ANGELES

Lead in blood, mg/100g	Aircraft employees		Los Angeles policemen	Pasadena City employees	
	Male	Female		Male	Female
0 -0.009	25	12	3	16	19
0.010-0.019	148	53	57	31	23
0.020-0.029	86	16	83	25	9
0.030-0.039	17	3	11	13	1
0.040-0.049	10	2	1	3	
0.050-0.059	1	1			
0.060-0.069	3				
0.070-0.079	1				
Totals	291	87	155	88	52
Mean	0.010	0.017	0.021	0.019	0.012
Std. dev.	0.010	0.009	0.006	0.011	0.009

TABLE 32
DISTRIBUTION OF MALES IN VARIOUS OCCUPATIONAL
GROUPS ACCORDING TO CONCENTRATION
OF LEAD IN URINE—LOS ANGELES

Lead in urine, mg/l	Aircraft employees	Los Angeles policemen	Pasadena City employees
0 -0.009	112	18	27
0.010-0.019	85	54	29
0.020-0.029	54	37	14
0.030-0.039	13	13	4
0.040-0.049	4	7	2
0.050-0.059	3	3	2
0.060-0.069	0	1	0
0.070-0.079	1		1
Totals	272	133	79
Mean	0.014	0.021	0.017
Std. dev.	0.011	0.013	0.013

TABLE 33
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
SUBJECTS BY AREA OF RESIDENCE—LOS ANGELES

Area of residence	Lead in blood			Lead in urine		
	No. of sub-jects	Mean, mg/100g	Std. dev.	No. of sub-jects	Mean, mg/l	Std. dev.
Aircraft employees:						
Male total:	291	0.019	0.010	272	0.014	0.011
Coastal area	197	0.019	0.011	185	0.013	0.011
Central area	57	0.020	0.007	54	0.017	0.011
Inland area	37	0.020	0.010	33	0.015	0.015
Female total:	87	0.017	0.009			
Coastal area	67	0.017	0.009			
Central area	17	0.015	0.007			
Inland area	3	0.020	0.019			
Los Angeles policemen:						
Male total:	155	0.021	0.006	133	0.021	0.013
Coastal area	30	0.022	0.007	26	0.025	0.013
Central area	22	0.020	0.006	19	0.022	0.017
Inland area	103	0.021	0.006	88	0.019	0.011
Pasadena City employees:						
Male total:	88	0.019	0.011	79	0.017	0.013
Coastal area	1	0.000	—	0	—	—
Central area	0	—	—	0	—	—
Inland area	87	0.019	0.011	79	0.017	0.013
Female total:	52	0.012	0.009			
Coastal area	0	—	—			
Central area	1	0.002	—			
Inland area	51	0.012	0.009			

are found in the police group. The highest values of lead in the blood for females in both groups are lower than the comparable values for the males.

Table 33 gives results of subdividing the basic groups in terms of their residence in the coastal, central, or inland areas of greater Los Angeles. Individuals were classified in the residential area in which they lived for the longest period of time between 1956 and 1961. No significant differences in lead levels were observed in these subgroups.

TABLE 34
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
SUBJECTS BY SMOKING HABITS—LOS ANGELES

Classification of subjects	Lead in blood			Lead in urine		
	No. of subjects	Mean, mg/100g	Std. dev.	No. of subjects	Mean, mg/l	Std. dev.
Aircraft employees:						
Male total:	291	0.019	0.010	272	0.014	0.011
Smokers:						
Cigarettes	137	0.022	0.010	129	0.015	0.013
Other	33	0.017	0.007	31	0.015	0.014
Nonsmokers	121	0.018	0.011	112	0.013	0.009
Female total:	87	0.017	0.009			
Smokers:						
Cigarettes	55	0.019	0.009			
Other	0	—	—			
Nonsmokers	32	0.014	0.007			
Los Angeles policemen:						
Male total:	155	0.021	0.006	133	0.021	0.013
Smokers:						
Cigarettes	85	0.022	0.006	76	0.022	0.012
Other	15	0.016	0.009	13	0.017	0.008
Nonsmokers	55	0.020	0.005	44	0.020	0.014
Pasadena City employees:						
Male total:	88	0.019	0.011	79	0.017	0.013
Smokers:						
Cigarettes	45	0.020	0.011	39	0.020	0.014
Other	6	0.021	0.014	5	0.026	0.027
Nonsmokers	37	0.018	0.010	35	0.012	0.007
Female total:	52	0.012	0.009			
Smokers:						
Cigarettes	9	0.012	0.007			
Other	0	—	—			
Nonsmokers	43	0.012	0.009			

The effects of smoking on lead levels were examined in the five employee groups; the results are presented in Table 34. The group labeled "smokes cigarettes" included all respondents who currently smoked cigarettes. The smokers labeled "other" included current smokers of pipes or cigars who did not smoke cigarettes at the time of the study. The "nonsmokers" included individuals who had never

smoked or who were currently nonsmokers. Again, although the differences are small, lead levels are generally somewhat higher in smokers of cigarettes than in nonsmokers or those who smoke pipes or cigars. The only exceptions are the Pasadena female group, in which mean

TABLE 35
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
SUBJECTS BY COMMUTING TIME—LOS ANGELES

Commuting time, minutes	Lead in blood			Lead in urine		
	No. of sub- jects	Mean, mg/ 100g	Std. dev.	No. of sub- jects	Mean, mg/l	Std. dev.
Aircraft employees:						
Male total:	291	0.019	0.010	272	0.014	0.011
0- 9	37	0.019	0.012	33	0.014	0.011
10-29	130	0.019	0.011	125	0.014	0.011
30-59	99	0.020	0.009	94	0.014	0.012
60+	24	0.018	0.008	19	0.011	0.009
Not Stated	1			1		
Female total:	87	0.017	0.009			
0- 9	12	0.014	0.006			
10-29	46	0.017	0.009			
30-59	25	0.017	0.008			
60+	2	0.026	0.023			
Not Stated	2					
Los Angeles policemen:						
Male total:	155	0.021	0.006	133	0.021	0.013
0- 9	5	0.021	0.002	5	0.017	0.011
10-29	85	0.021	0.006	69	0.020	0.012
30-59	59	0.021	0.007	53	0.023	0.014
60+	3	0.020	0.004	3	0.026	0.003
Not Stated	3			3		
Pasadena City employees:						
Male total:	88	0.019	0.011	79	0.017	0.013
0- 9	10	0.024	0.009	9	0.014	0.017
10-29	61	0.019	0.011	56	0.017	0.013
30-59	16	0.019	0.011	14	0.017	0.011
60+	1	0.000		0		
Female total:	52	0.012	0.009			
0- 9	12	0.012	0.009			
10-29	36	0.012	0.009			
30-59	3	0.012	0.010			
60+	1	0.019				

lead levels in the blood of smokers and nonsmokers are the same, and the Pasadena male group, in which levels are higher for pipe and cigar smokers than for the cigarette smoking group. Here again, lead levels in the blood of females are consistently somewhat lower than those of their male counterparts, by smoking groups.

Table 35 shows the mean lead values in blood and urine according to sex, employment group, and commuting time. There is no progression of values with increasing commuting time in any employment group.

For policemen, the mean and standard deviations of lead values in blood and urine are shown in Table 36, by type of duty. The subgroup assigned to parking and intersection work shows slightly higher mean lead values for both blood and urine than the motorcycle subgroup.

The possible relationships of the lead levels in blood and urine to occupation and to medical history were explored. No significant correlations were found.

TABLE 36
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
POLICEMEN BY TYPE OF DUTY—LOS ANGELES

Duty classification	Lead in blood			Lead in urine		
	No. of sub-jects	Mean, mg/100g	Std. dev.	No. of sub-jects	Mean, mg/l	Std. dev.
TOTAL	155	0.021	0.006	133	0.021	0.013
Motorcycle	62	0.020	0.006	55	0.019	0.009
Parking and Intersection	93	0.022	0.006	78	0.022	0.015

Chronic disease patients: Table 37 shows the individual lead values for the blood and urine of a number of patients with chronic medical conditions studied at a hospital for treatment of chronic diseases and at an outpatient clinic in Los Angeles. In some cases, as indicated, more than one condition was present and for this reason the classification is to some extent an arbitrary one. Neither the ranges of individual values nor the means of lead concentrations in the blood in the grouped cases are remarkable. These limited and exploratory data yield no suggestion that illnesses of these types result in any special abnormalities in the metabolism of lead.

Philadelphia

Populations Studied: In Philadelphia, a volunteer group of 113 individuals exposed to community atmospheric lead in normal working

TABLE 37
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
SELECTED CHRONIC-DISEASE PATIENTS—LOS ANGELES

Sex	Age, years	Respiratory conditions			Kidney conditions			Bone conditions		
		Lead in blood, mg/ 100g	Lead in urine, mg/l	Addi- tional condi- tions	Lead in blood, mg/ 100g	Lead in urine, mg/l	Addi- tional condi- tions	Lead in blood, mg/ 100g	Lead in urine, mg/l	Addi- tional condi- tions
M	15				0.022					
F	26				0.028					
M	29									
F	33				0.014			0.019		
M	33				0.013					
F	34	0.004		Kidney						
M	35				0.010					
M	36				0.028					
M	40				0.009					
M	43	0.007					Bone			
M	44									
F	45				0.023			0.008		Liver
M	46				0.024					
M	48	0.025	0.019							
M	48	0.034	0.041							
F	51				0.013					
M	53	0.018	0.018							
M	56				0.054	0.027				
F	56				0.022					
F	56				0.025					
M	56				0.011		Bone, resp.			
M	57	0.012								
M	57	0.022								
M	59	0.050		Kidney						
M	59							0.020		
M	59				0.007	0.044				
M	59				0.006					
M	62	0.046								
F	64	0.041		Kidney						
F	64				0.003					
M	65	0.038	0.006							
F	65	0.023								
M	65	0.012								
M	65				0.004					
M	66	0.010								
M	67							0.019		Heart, resp.
F	67				0.024					
F	69							0.022		
F	74							0.010		
M	74				0.006					
M	75	0.028	0.019							
M	76	0.000								
F	80				0.000		Heart, bone			
F	83							0.006		
F	87							0.024		
F	88							0.017		Heart
F	89							0.033		Resp.
F	91							0.019		Heart, resp.
F	98									
M	—	0.025						0.004		
Mean:		0.023			0.018			0.014		

environment was obtained from the Philadelphia Police Department. About 60 percent of these men were members of the foot traffic division, who served on duty at busy intersections for not less than 5 years and in many instances much longer. The remaining 40 percent were officers engaged in patrol-car duty in the downtown section of the city. The residences of the individual officers were situated in all areas of the city. A second group consisted of 106 individuals who had lived and worked within a 25-block radius of the Philadelphia City Hall for a minimum of 5 years. A third group comprised 50 suburban commuters who had lived in an outlying section of the city for at least 5 years and commuted daily to work in the downtown Philadelphia area. Another group of 81 suburban subjects was made up of persons who had lived in the same section of the city as the suburban commuters for at least 5 years, but who normally spent their entire time in that neighborhood. A final group of 75 consisted of subjects known to have chronic diseases of the liver, kidney, bone, and lung, which might affect lead levels in blood and urine. These individuals were outpatients at the Pennsylvania, Philadelphia General, and Jefferson hospitals.

Results: Tables 38 and 39 show the frequency distributions of the concentrations of lead in the blood and urine of the various groups. As the area of residence shifts from the core of the city toward the suburbs, concentrations of lead in the blood tend consistently downward.

TABLE 38
DISTRIBUTION OF SUBJECTS ACCORDING TO THE
CONCENTRATION OF LEAD IN BLOOD—PHILADELPHIA

Lead in blood, mg/100g	Suburban		Commuter		Downtown		Police
	Male	Female	Male	Female	Male	Female	
0 -0.009	6	14	5	1	2	4	0
0.010-0.019	14	39	17	5	12	24	17
0.020-0.029	3	2	16	1	37	9	70
0.030-0.039		3	4		12	3	22
0.040-0.049			1		3		4
Totals	23	58	43	7	66	40	113
Mean	0.013	0.013	0.019	0.015	0.024	0.018	0.026
Std. dev.	0.005	0.007	0.009	0.004	0.008	0.007	0.006

Levels for the downtown police group were slightly higher than for the downtown males. With the exception of the suburban area, males show higher levels of lead in their blood than comparable females.

TABLE 39
DISTRIBUTION OF MALES ACCORDING TO
CONCENTRATION OF LEAD IN URINE—PHILADELPHIA

Lead in urine, mg/l	Suburban	Commuter	Downtown	Police
0 -0.009	5	5	3	2
0.010-0.019	4	6	12	18
0.020-0.029	7	11	12	28
0.030-0.039	1	6	13	26
0.040-0.049	1	1	8	24
0.050-0.059	1	2	4	8
0.060-0.069		2	0	7
0.070-0.079		0	1	
0.080-0.089		1		
Totals	19	34	53	113
Mean	0.020	0.028	0.030	0.033
Std. dev.	0.014	0.019	0.015	0.014

Table 40 presents the lead levels in the blood and urine of smokers and nonsmokers in the population groups. In all groups except the downtown females, mean values are slightly higher for smokers than for nonsmokers. In all groups except suburban, levels are lower for females than for male counterparts.

Lead levels in the blood and urine of the police group classified by age are tabulated in Table 41. The lead levels in blood showed no trend with age. Lead levels in urine decreased irregularly with age.

To quantitate the relationships among the various factors and the concentrations of lead in the blood, an exact "weighted" analysis of variance was performed on the cells of a four-factor cross-classification based upon age, sex, smoking, and group. Before the analysis, data obtained for downtown males and police were pooled, and all analytical findings were transformed to logarithms to the base 10. The log-transformation was performed because the frequency histograms were more normally distributed when plotted on a logarithmic scale. A report by Horiuchi and Takada supports the appropriateness of such a transformation when dealing with probability statements about mean lead concentrations in blood.¹¹

TABLE 40
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
SUBJECTS CLASSIFIED BY SMOKING HABITS—PHILADELPHIA

Classification	Lead in blood			Lead in urine		
	No. of subjects	Mean, mg/100g	Std. dev.	No. of subjects	Mean, mg/l	Std. dev.
Suburban						
Males	23	0.013	0.005	19	0.020	0.014
Smokers	14	0.015	0.005	12	0.026	0.014
Nonsmokers	9	0.011	0.006	7	0.009	0.005
Females	58	0.013	0.007			
Smokers	22	0.016	0.008			
Nonsmokers	36	0.011	0.006			
Commuter						
Males	43	0.019	0.009	34	0.028	0.019
Smokers	33	0.021	0.008	26	0.029	0.021
Nonsmokers	10	0.013	0.006	8	0.027	0.016
Females	7	0.015	0.004			
Smokers	4	0.018	0.004			
Nonsmokers	3	0.012	0.003			
Downtown						
Males	66	0.024	0.008	53	0.030	0.015
Smokers	55	0.025	0.008	43	0.030	0.015
Nonsmokers	11	0.022	0.008	10	0.029	0.012
Females	40	0.018	0.007			
Smokers	29	0.018	0.007			
Nonsmokers	11	0.018	0.006			
Police	113	0.026	0.006	113	0.033	0.014
Smokers	83	0.026	0.007	83	0.034	0.015
Nonsmokers	30	0.024	0.005	30	0.028	0.013

TABLE 41
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF
POLICE CLASSIFIED BY AGE—PHILADELPHIA

Age, years	Lead in blood			Lead in urine		
	No. of subjects	Mean, mg/100g	Std. dev.	No. of subjects	Mean, mg/l	Std. dev.
20-29	17	0.027	0.006	17	0.039	0.013
30-39	56	0.027	0.006	57	0.032	0.014
40-49	29	0.024	0.006	29	0.034	0.015
50-59	10	0.027	0.008	9	0.030	0.011
60+	1	0.021		1	0.025	

The results of this analysis are given in Table 42. The relationships between the mean concentrations of lead in blood and both smoking and composition of group were statistically significant, the relationship between lead in blood and sex was of questionable significance; and that with age, of no significance.

A more detailed comparison of males and females with respect to lead concentrations was made with the Student's "t-test" in each group. The tests were made separately for smokers and nonsmokers, after the pooling of data pertinent to the various age groups. Several of the more important tests are shown in Table 43. Only in the downtown groups did the mean concentrations of lead in the blood of comparable groups of males and females differ significantly.

The presence of an interaction effect for smoking and group as shown in Table 42 reflects the overall pattern of results with regard to these variables. In the male downtown groups, area of activity is associated with higher concentrations of lead in the blood, and there is no detectable association with smoking. Among the suburban groups, smoking is associated with higher concentrations of lead in the blood. Smoking affects both suburban commuters and suburban noncommuters. Commuting has no effect on nonsmokers, but a combination of commuting and smoking has a greater effect than smoking alone.

This pattern can be explained by the assumption that the smoking-associated effect is, on the average, of equal magnitude among the groups, and therefore of decreasing relative significance as the concentration of lead in the blood increases. The urban-associated effect, however, increases in magnitude and in relative significance as one progresses toward the core of the city, where the average concentration of lead in the blood is highest.

In addition to samples from the population groups already discussed, blood (and some urine) specimens from several groups of patients from a dispensary in Philadelphia were analyzed. These patients were selected because they suffered from certain types of chronic illnesses. The results are presented in Table 44. Neither the ranges nor mean levels of lead in the blood from the four disease groups are remarkably high or low.

Discussion of Biological Investigations in the Three Cities

In the combined data here reported, concentrations of lead in the blood were determined for a total of 2,342 individuals. Of these, 2,216 were normal individuals, and 126 were selected patients with various chronic diseases. Of the normal population group, 478 had been studied in a previous survey in Cincinnati in 1956, and 211 had been examined during pilot studies in California. Of this number, only 11 persons were found to have concentrations of lead in the blood equal to or in excess of 0.06 milligrams per 100 grams of blood. Five of these results were

TABLE 42

ANALYSIS OF VARIANCE TO DETERMINE WHETHER SIGNIFICANT DIFFERENCES OCCUR
IN THE MEAN LEVELS OF LEAD IN BLOOD OF SELECTED GROUPS IN PHILADELPHIA

Effects	Sum of squares	Degrees of freedom	Variance	F-ratio	Significance level 1% 10%
Main effects:					
H = Smokers vs nonsmokers	0.437306	1	0.437306	14.02	yes yes
A = Between age groups	0.016660	2	0.008330	0.27	
G = Between groups	1.500619	2	0.750310	25.01	yes yes
S = Males vs females	0.118630	1	0.118630	3.80	yes
Two-factor interaction effects:					
H,A	0.001708	2	0.000854	0.03	
H,G	0.234352	2	0.117176	4.72	yes yes
H,S	0.019714	1	0.019714	0.63	
A,G	0.105294	4	0.026324	0.85	
A,S	0.106230	2	0.053115	1.70	
G,S	0.045606	2	0.022803	0.73	

also interaction between two factors measures the variability of the effect of the first factor among levels of the other factor.

TABLE 43
COMPARISON OF MEAN CONCENTRATIONS OF LEAD IN BLOOD
BY USE OF STUDENTS' "t-TEST"—PHILADELPHIA
(IN MILLIGRAMS OF LEAD PER 100 GRAMS OF BLOOD)

	Smokers	Non-smokers	Average
Police downtown (Male)	(1) 0.0245 ^a	(2) 0.0226	(3) 0.0240 ["t" (1, 2) = 1.34 ^b (1), (2) are averageable]
Female	(4) 0.0167	(5) 0.0182	(6) 0.0171 ["t" (4, 5) = 0.64 ^b (4), (5) are averageable]
Average	["t" (1, 4) = 5.53 ^b (1), (4) are not averageable]	["t" (2, 5) = 1.83 ^b (2), (5) are not averageable]	
Suburban commuter (Male and female)	(7) 0.0156	(8) 0.0117	["t" (7, 8) = 2.80 ^b (7), (8) are not averageable]
Suburban (Male and female)	(9) 0.0141	(10) 0.0101	["t" (9, 10) = 2.80 ^b (9), (10) are not averageable]
Average	["t" (7, 9) = 2.29 ^b (7), (9) are not averageable]	["t" (8, 10) = 0.91 ^b (8), (10) are averageable] Average = 0.0105	

^aConcentrations indicated are geometric means.

^b"t-Test" does not show a difference between (x) and (y) at the 10% level of significance.

^c"t-Test" does show a difference between (x) and (y) at the 10% level.

TABLE 44
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF SELECTED
CHRONIC-DISEASE PATIENTS—PHILADELPHIA

Sex	Age, yr	Respiratory conditions		Kidney conditions		Bone conditions		Liver conditions	
		Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l
M	14			0.022					
F	18	0.014							
F	20			0.027					
F	23	0.011							
F	28	0.016							
M	29			0.021					
F	34							0.017	
F	35			0.009					
F	36	0.052							
M	36			0.019				0.043	0.014
M	37				0.049				
M	38							0.021	0.031
M	41							0.025	
F	42			0.019					
F	42			0.012					
M	42			0.021	0.053				
M	42	0.034	0.031						
M	43					0.020			
F	49			0.011					

TABLE 44 Continued
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF SELECTED
CHRONIC-DISEASE PATIENTS—PHILADELPHIA

Sex	Age, yr	Respiratory conditions		Kidney conditions		Bone conditions		Liver conditions	
		Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l
M	50							0.029	0.012
M	50							0.049	0.046
M	50	0.020	0.022						
M	51								
F	52							0.026	0.025
M	54							0.010	
M	55	0.040		0.013	0.015				
F	55	0.017							
M	55	0.056							
M	56								
M	57	0.015	0.014					0.018	0.011
F	57			0.016					
M	58								
M	58	0.037	0.004					0.020*	
M	59	0.036							
F	59					0.015			
M	60	0.037							
M	60							0.022	0.020
M	61							0.015	0.010

TABLE 44 Continued
 CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF SELECTED
 CHRONIC-DISEASE PATIENTS—PHILADELPHIA

Sex	Age, yr	Respiratory conditions		Kidney conditions		Bone conditions		Liver conditions	
		Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l
M	61							0.014	0.013
M	62							0.018	
F	62			0.010					
F	63			0.023					
F	63					0.021			
F	64			0.027					
M	64	0.029							
M	66	0.016	0.003						
M	66	0.021							
M	67							0.027	
M	68	0.019	0.031						
M	68	0.020							
F	68	0.012							
F	68							0.030	
M	68							0.020	
F	69							0.016	
M	69	0.018	0.020						
M	71	0.018	0.023						
M	72	0.012 ^b	0.006 ^b						

TABLE 44 Continued
CONCENTRATIONS OF LEAD IN BLOOD AND URINE OF SELECTED
CHRONIC-DISEASE PATIENTS—PHILADELPHIA

Sex	Age, yr	Respiratory conditions		Kidney conditions		Bone conditions		Liver conditions	
		Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l	Lead in blood, mg/100g	Lead in urine, mg/l
M	72	0.014							
F	72	0.014							
M	72								
M	72			0.031				0.018	0.007
M	72								
M	73			0.012		0.017			
M	73	0.042							
M	75								
F	77			0.019					
F	78								
F	78					0.023			
M	78					0.022			
F	79					0.012			
F	79					0.022	0.005		
F	79					0.014			
M	80	0.022				0.010			
M	80	0.027	0.041						
M	80								
M	81					0.016			
F	87					0.022			
						0.023			
Mean		0.024		0.018		0.019		0.023	

^aPatient also suffering from lung condition.

^bPatient also suffering from kidney condition.

obtained in Cincinnati in the survey of 1956 (four garage mechanics and one parking attendant), two in Cincinnati in the present survey (one traffic policeman and one post-office employee), and four in Los Angeles (male employees of an aircraft manufacturer). These 11 persons were from groups which had an opportunity for occupational exposure to lead. A small percentage of values equal to or in excess of 0.006 is to be expected in such groups. An additional 30 persons (25 garage mechanics, 1 post office employee, 2 service station attendants, and 2 employees of an aircraft manufacturer) had concentrations of lead in the blood between 0.05 and 0.06. Again most of these individuals were from groups with potential occupational exposure to lead.

Levels of lead were determined in the urine of 1,668 males in the group of 2,342 individuals. These urine values fall within the fairly narrow range that is defined presently as "normal." Of the highest values, 11 were equal to or in excess of 0.08 milligram per liter and 23 were equal to or in excess of 0.07.

Levels of lead in the blood were analyzed in relation to a number of variables. In relation to the geographic location of residence and place of work, the Philadelphia data show an increasing gradation of the levels of lead in the blood from the suburban through the commuter to the urban group. The rural group examined in the California pilot study shows the lowest levels. In the Cincinnati and Los Angeles groups, no notable gradation in relation to geographic location is apparent. In addition, the Los Angeles data show no relation between lead levels and commuting time. This aspect was not examined in the other two cities.

Within the study groups selected, particularly in Cincinnati, several occupational groups are included that were selected because of their probable exposure at work to high levels of automobile exhaust. Policemen were examined in all three cities, and commercial drivers and parking attendants were included in the Cincinnati study. In addition, garage mechanics, who as a group are exposed to lead in a variety of ways other than that derived from automobile exhaust, were investigated again as they had been in previous surveys in Cincinnati. All of these groups showed levels of lead in blood and urine that were higher than those found in the blood and urine of persons in ordinary occupations. This was evident in the garage mechanics in particular, and in a small group of parking attendants. In Los Angeles and Cincinnati, policemen concerned with traffic direction at busy intersections showed somewhat higher levels of lead than other police. Aside from the specific occupational categories given above, the mean concentrations of lead showed no correlation with occupational histories obtained from all individuals in Los Angeles and Cincinnati. There was also no evidence of a relationship between the lead levels and specific items in the medical histories.

The possibility of a relationship between the lead levels and age was examined in two groups in Cincinnati and one in Philadelphia. No relationship was found. The levels of lead in the urine of Philadelphia police show some tendency to decline in the older age groups. The values here are small, and the trend is opposite to that which would be expected if any accumulation were occurring with age.

With one exception (suburban Philadelphia), the levels of lead in the blood of females are slightly lower than those found in comparable males. Nothing in these data, e.g., smoking or work, suggests an explanation for this observation. The differences are not great, but are remarkably consistent. These studies were not designed to investigate this particular problem. Special studies to determine whether such differences are due to intrinsic or extrinsic factors would be desirable.

These studies provide some information about the variable of smoking, although again, they were not designed to examine this factor specifically. The limited material available indicates that further examination of this problem must be designed especially for this purpose. In nearly all instances smokers showed slightly higher lead levels than nonsmokers. The small amount of information obtained on type and amount of smoking was insufficient to yield conclusions.

These observations show several interesting gradations, even though the values are well within the presently accepted normal range of lead levels in humans. The levels of lead in blood tend to increase gradually as the place of residence and work varies from rural to central urban areas. A second gradation is found in relation to increasing opportunity for occupational exposure to exhausts of automobiles. All of these variables—sex, smoking habits, and exposure to automobile exhaust, appear to be independent of each other.

In Philadelphia and Los Angeles selected groups of patients ill with chronic disease of the lungs, bones, kidneys and liver, were examined to determine the level of lead in the blood. This was done to ascertain whether there was evidence of unusually high or low levels in any of these diseased groups that would indicate the need for further study. No unusual findings were obtained.

In the course of these investigations, some actually or potentially pertinent factors were not examined in detail. The most important, as discussed previously in this report, are lead intakes in food and in water. These could logically influence the minor differences observed in the levels of lead in the blood and urine.

In addition, the size of the particle of airborne lead and the seasonal variations in the metabolism of lead were not examined.

RELATION OF BIOLOGICAL FINDINGS TO ATMOSPHERIC RESULTS

One of the objectives of this study was to ascertain whether detectable differences exist in the lead content of blood and urine of people who are subject to exposure of different concentrations of lead in the atmosphere.

The difficulties in assessing a relationship of this nature were described in earlier portions of this report. In its simplest form the problem is to determine: (1) whether variations such as were found in the lead content of the blood and urine are due to variations in the concentration of lead in the atmosphere or to variations in the quantities ingested in food and beverages or a combination of these two variables, and (2) how the composite respiratory exposure to lead for a mobile population can be determined. If only random population groups were considered, differences in the mean concentrations of lead in blood and urine could not be ascribed either to ingestion or inhalation. In this investigation, however, random selections were not made. Some 25 male population groups were selected with respect to their supposed exposure to varying concentrations of atmospheric lead.

Table 45 shows the male groups for which values of lead in the blood were obtained. The groups are arranged in order of their mean values of lead in blood. There is about a four-fold difference (0.009 to 0.038 mg Pb/100g blood) in these values, and there appears to be an orderly progression in values according to the most likely concentration of lead in the atmosphere to which these groups were exposed. For example, the lowest concentrations were found in the suburban and rural groups; intermediate concentrations, in the downtown employees; and the highest concentrations were found among drivers of cars and parking attendants.

Although some of these groups, such as garage mechanics, service station attendants, and refinery handlers of gasoline, are exposed to lead in their occupations as well as to lead in the atmosphere, they are listed in Table 45 to show comparative levels of lead in the blood. Also the possibility that the variability of the amounts of lead ingested with food and beverages accounts for some of the differences cannot be ignored. It is important to recognize that the differences between the lowest and the highest of the groups, while relatively large, are well within the presently accepted range of lead levels for humans and are not significant in terms of a threat of the occurrence of lead intoxication within the groups.

TABLE 45
SUMMARY OF CONCENTRATIONS OF LEAD IN BLOOD
OF SELECTED GROUPS OF MALES^a

Mean, mg/100g	No. of Subjects	Identity of Group
0.011	9	Suburban nonsmokers, Philadelphia
0.012	16	Residents of rural California county
0.013	10	Commuter nonsmokers, Philadelphia
0.015	14	Suburban smokers, Philadelphia
0.019	291	Aircraft employees, Los Angeles
0.019	88	City employees, Pasadena
0.021	33	Commuter smokers, Philadelphia
0.021	36	City Health Dept. employees, Cincinnati
0.021	155	Policemen, Los Angeles
0.022	11	Live and work downtown, nonsmokers, Philadelphia
0.023	140	Post-office employees, Cincinnati
0.024	30	Policemen, nonsmokers, Philadelphia
0.025	191	Firemen, Cincinnati
0.025	123	All policemen, Cincinnati
0.025	55	Live and work downtown, smokers, Philadelphia
0.026	83	Police, smokers, Philadelphia
0.027	86	Refinery handlers of gasoline, Cincinnati (1956)
0.028	130	Service station attendants, Cincinnati (1956)
0.030	40	Traffic police, Cincinnati
0.030	60	Tunnel employees, Boston
0.031	17	Traffic police, Cincinnati (1956)
0.031	14	Drivers of cars, Cincinnati
0.033	45	Drivers of cars, Cincinnati (1956)
0.034	48	Parking lot attendants, Cincinnati (1956)
0.038	152	Garage mechanics, Cincinnati (1956)
	1877	Total

^aValues are those determined in the present study, except where otherwise indicated.

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APPENDIX

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